A System Dynamics Approach to the Political Economy of Resource-dependent Nations

by

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Abstract

Development on the basis of extraction and export of natural resources is a dynamically complex problem. Empirical evidence shows that while some nations have been successful to translate natural resource wealth into long-term development but many have failed too. In this dissertation a system dynamics approach is taken to understand why this is happening and what strategies could facilitate a resource-based development process. In this regard, Mashayekhi's model of oil-dependency of Iranian economy as one of the few relevant system dynamics examples is updated and revalidated. The results show that despite its capability in showing the dynamics of the problem from an economic perspective it lacks socio-political features that are necessary to address the most fundamental issues of resource-based development. It is shown that Katouzian's theory of "arbitrary state and society" could fill this gap. The theory is, thus, translated into a system dynamics model so that it could be tested for internal consistency and used for policy analysis. The model is able to explain long-term socio-political-economic instability of a resource-dependent society. On the basis of Mashayekhi's model, Katouzian's theory, and other fundamental explanations of natural resource dependency that are available from the literature, a generic eclectic model is developed. The model has gone through a comprehensive list of confidence-building tests. Controlled experimentation through Monte Carlo simulations show that, on the contrary to the current belief, it is unlikely that natural resource wealth be harmful for social welfare. Results also revealed that rule of law is a crucial factor that affects trajectory of the socio-political-economic development. Other findings are as follow. Civil resistance (disobedience) can be harmful for the system in the long-run. While sanctions could affect the economy it has barely an impact on socio-political settings of a society. Finally, wage stabilization, facilitation of social mobility, and privatization of natural resource revenues (within certain limits) could help the resource-based development to achieve better outcomes.

Preface

Development on the basis of extraction and export of natural resources is a dynamically complex problem. It is still a common belief that natural resource abundance is a "curse" than a "blessing." Even among academics no consensus has been reached over the issue. This is perhaps because of the intrinsic nature of the problem. In fact, many factors come into play to determine ultimate developmental outcome of natural resource dependency, namely, social, political, and economic factors. So far, there has been no comprehensive study that could take all these facets into account. This is indeed a theoretical gap. Advancement in computer technologies which made the numerical simulation of large models possible and led to methodological improvements in the social sciences has enabled us to overcome this challenge though. The dissertation presented here takes this advantage and bridges the gap by taking a system dynamics approach to improve our understanding of resource-based development. Hopefully, this will shed some light on the issue and help us to develop better strategies and policies for the next generations who may be affected by the long-term consequences of natural resource dependency.

Although the nature of the resource curse problem urges for a dynamical systems perspective, but little system dynamics modeling effort has been made to shed light on the issue. Mashayekhi's model of Iranian oil-based economic development (Mashayekhi, 1978) is one of these efforts. It is unique in the sense that it captures complex economic dynamics of natural resource dependency in "developing" countries. In order to investigate the natural resource curse problem the first step was to examine the existing theories instead of reinventing the wheel. In this regard, Mashayekhi's model had to be updated and revalidated. It was not an easy task though. The original model was written with DYNAMO[1] which is not in use anymore. So, to test the model it must had been reprogrammed in a modern platform. I rewrote the model in modern system dynamics software and updated all units of measure and documentations. The revived model has gone through a comprehensive validation tests. This effort is reported in Chapter 1. Test results show that despite its capability in replicating dynamics of the problem from an economic perspective, the model lacks socio-political features that are necessary to address the most fundamental

[1]DYNAMO is a computer simulation language developed in the late 1950s within the system dynamics analytical framework (Richardson and Pugh III, 1981; Pugh III, 1983).

issues of resource-based development. More precisely, the model is unable to endogenously reproduce rise and fall of political power that may happen in a social system. This socio-political dynamic is particularly essential for the problem of natural resource curse. It may arise from a natural resource bonanza and it can significantly affect phenomena such as corruption, chaos, freedom, institutional development, etc. which eventually propagate through the economic system too and affect the social welfare.

Fortunately, there is Katouzian's theory of "arbitrary state and society" that could fill the gap. It includes most fundamental structures needed for a socio-political analysis of a natural resource curse. In particular, Katouzina's theory is able to explain long-term socio-political-economic instability of a resource-dependent society. However, this theory is descriptive, not mathematical. For it to be formally tested it required to be transformed into a mathematical format. Hence, I translated it into a system dynamics model so that it could be tested for internal consistency and used for policy analyses. Chapter 2 reports the translation process and the test results. Examination with the model reveals that Katouzina's theory is internally consistent and its structure can be used to enhance explanatory power of economic models of natural resource curse. Results also revealed that rule of law is a crucial factor that affects trajectory of the socio-political-economic development while civil resistance (disobedience) can be harmful for the system in the long-run. And, economic sanctions could negatively affect the economy but it has barely an impact on socio-political settings of a society.

On the basis of Mashayekhi's model, Katouzian's theory, and some other important theories, I developed a generic eclectic model for political economy of natural resource dependency. In fact, the model takes into account 7 different explanations of natural resource "curse." The explanations are "Dutch disease," "temporary loss in learning by doing," "corruption," "volatility of commodity prices," "rent seeking behavior," "socio-political conflict," and "suboptimal policies." The model has gone through a comprehensive list of confidence-building tests then. These are reported in Chapter 3. Controlled experimentation through Monte Carlo simulations show that on the contrary to the current belief, the chance of natural resource revenue being a "curse" is low. Finally, simulation results reveal that wage stabilization, facilitation of social mobility, and limited privatization of natural resource revenues might improve the outcome of a resource-based development.

At the end, I would like to thank Professor Michael Radzicki, my advisor, who patiently and carefully reviewed my work during (and even before) my doctoral program. This dissertation would not have happened if it had not been for his guidance. I am also indebted to professors, Alexander Smith, Rajib Malick, Nader Shetab Boushehri, Ali Mashayekhi, and Homa Katouzian for their valuable comments and advice throughout this journey. I am thankful to my friend and colleague, Raafat Zaini, with whom I have had the best (academic and non-academic) moments of my doctoral life. His encouragement and moral support during difficult times were a real blessing. My special thanks go to members of WPI's *System Dynamics Club* and participants of *Collective Learn-*

ing Meetings at the department of *Social Science & Policy Studies*, in particular, professor Oleg Pavlov, Timothy Clancy, James Hacunda, Christine Tang, Shiya Cao, Fredrick Kautz, and Raid Zaini from whom I have received great feedback and comments on my work. I am grateful to professors Khalid Saeed and Isa Bar-On for their support and mentoring without which the dissertation would not have been possible. My eternal gratitude goes to my parents who taught me lessons that are not offered by any academic courses. Finally, I cannot find words that could do justice to the thanks deserved by my wife, Mahsa. She sacrificed a lot for this dissertation to be finished.

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Chapter 1

Resurrecting a forgotten model: Updating Mashayekhi's model of Iranian economic development[1]

1.1 Introduction

In 1978, Ali Naghi Mashayekhi developed a system dynamics model to investigate the dependency of the Iranian economy on oil revenue (Mashayekhi, 1978). Although this study created a general awareness about Iranian oil-dependency among academics and politicians, the model itself has, by and large, been forgotten. The purpose of this chapter is to revisit and update Mashayekhi's model (the "M-model") and show that it deserves more attention. In particular, it will be demonstrated that the M-model has the potential to become a well-known starting point for future Iranian macroeconomic modeling efforts, especially in the area of energy–economy interactions. The M-model was created as a part of Mashayekhi's Ph.D. dissertation at the Massachusetts Institute of Technology. Simulations of the M-model in the late 1970s revealed that Iran would face a severe depression during the 1980s if its government pursued a policy of importing intermediate goods purchased with revenue from oil exports. Fig. 1.1.1 is a simulation run from the original formulation of the M-model that illustrates this potential crisis. It presents the base run time paths for Iranian oil reserves

[1] This chapter is published in "Energy Policy Modeling in the 21st Century, Understanding Complex Systems, pages 197–233. Springer New York, Jan. 2013. ISBN 978-1-4614-8605-3." edited by Hassan Qudrat-Ullah.

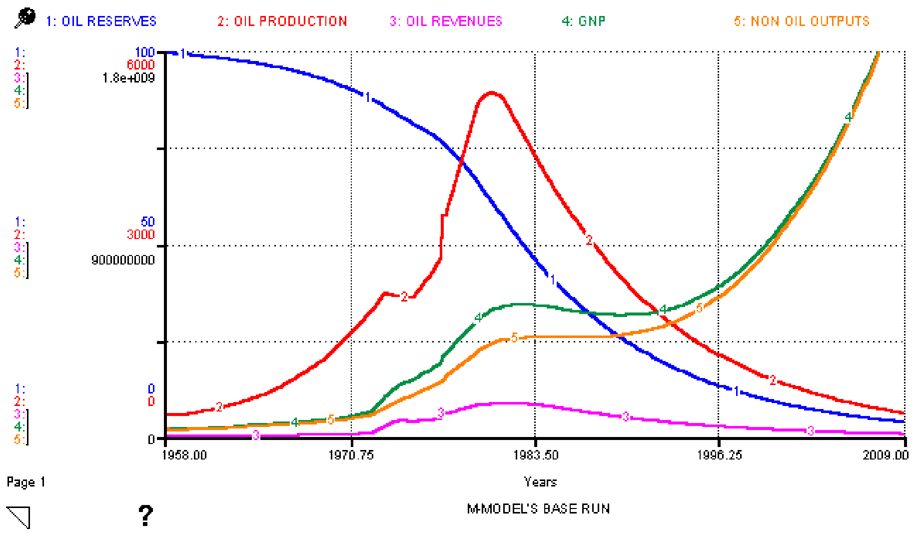

Figure 1.1.1: Base simulation run of the M-model

(curve 1) in terms of billion barrels, oil production (curve 2) in terms of million barrels per year, oil revenues (curve 3) in terms of million rials[2] per year, gross national product (GNP) (curve 4) in terms of million rials per year, and non-oil outputs (curve 5) in terms of million rials per year.

The dynamics of this base simulation run are as follows. Iranian oil revenue grows from the late 1950s to the early 1980s. In the middle of the 1980s, however, they begin to decline due to the depletion of Iranian oil reserves. Consequently, Iran's stock of foreign exchange begins to shrink and it begins to limit the importation of intermediate goods. The shortage of intermediate goods causes the production capacity of the economy to fall and the growth rate of non-oil output to approach zero, and even briefly turn negative, during the 1980s. The stagnation of both oil and non-oil output leads to a severe depression that lasts until beginning of the 1990s. In general, the M-model demonstrated that the high dependency of the Iranian economy on imports of intermediate goods, financed with oil revenue, would sooner or later cause Iran to run into serious economic difficulty. Although the specific scenario shown in Fig. 1.1.1 never occurred, the potential problems for the Iranian economy suggested by the M-model still exist. For example, Fig. 1.1.2 shows that during the period 1965–2008 the ratio of oil revenue to total revenue of the Iranian government ranged from 25 to 86%, with an average value of 57% (CBI, 2012). This situation was mitigated somewhat by a downward trend in the ratio during the years 1999–2008, although its value is currently hovering around its historical average.

[2]Rial is the Iranian currency unit.

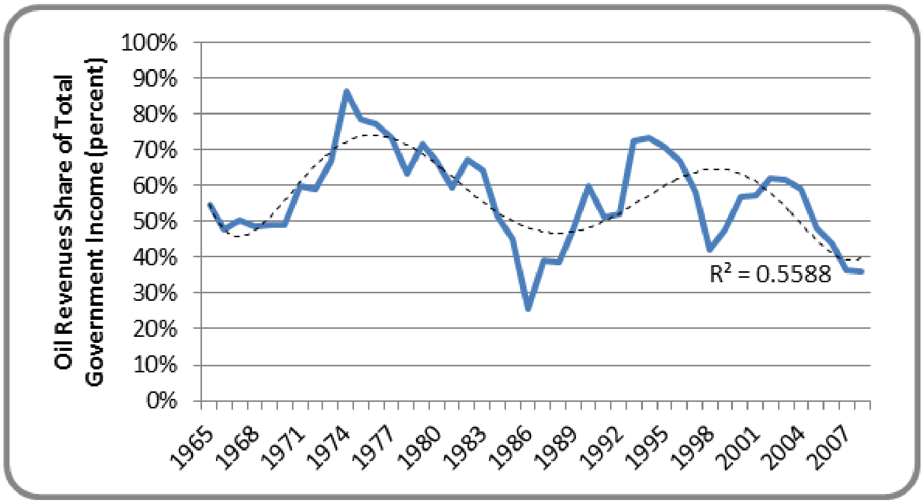

Figure 1.1.2: Oil's share of total Iranian government revenue (CBI, 2012)

At the same time, Fig. 1.1.3 shows that Iranian imports of raw material and intermediate goods have increased dramatically in recent years. From these data it is clear that Iran continues to be dependent on oil revenue and must import raw material and intermediate goods as aggressively as ever. As a consequence, it makes sense to update the M-model and restate its message so that Iranian policy makers can be reminded of the strategic issues it raises.

Although Mashayekhi was a pioneer in identifying the problems associated with the dependency of the Iranian economy on oil revenue, his model and its conclusions have arguably never received the attention they deserve. There are several reasons for this including:

- **The 1979 Revolution:** The creation of the M-model coincided with the birth of the 1979 Islamic revolution. The revolution led to fundamentally different decision making processes within the highest levels of Iranian political and economic institutions. As a consequence, the usefulness of the M-model became ambiguous. Moreover, in 1980, a year after the revolution's success, an eight-year war began when Iraq invaded Iran. This national emergency changed the Iranian government's priorities from economic reform to financing the war and stabilizing the political economy of the country (Ahmadi Amouee, 2006). Not surprisingly, few policy analysts paid attention to the oil-dependency issue during this period of time.

- **Unfamiliarity with System Dynamics:** The intellectual origin of system dynamics is engineering and management, not economics. As a consequence, most of economists in Iran were—and still are—unfamiliar with the system dynamics methodology. In fact, during the late 1970s there was virtually no one in Iran who could fully understand and appreciate

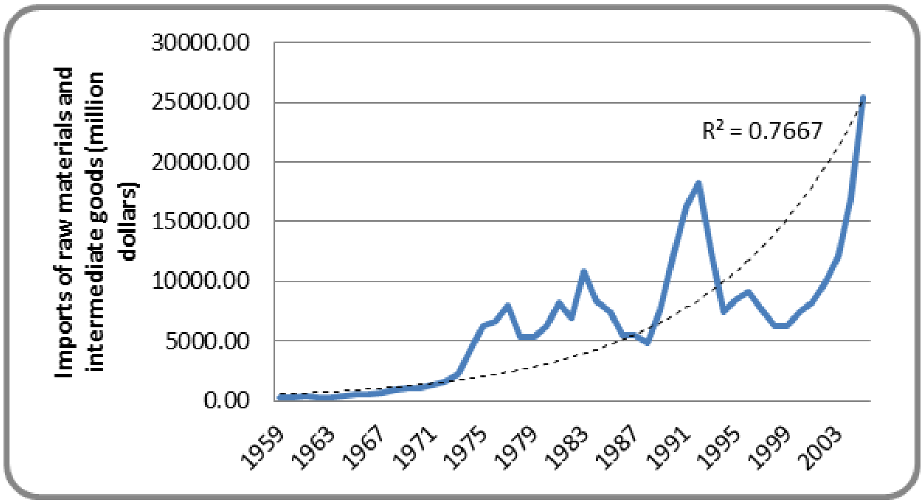

Figure 1.1.3: Iranian imports of raw materials and intermediate goods (CBI, 2012)

the M-model. Even now, there are few economists in Iran who know about system dynamics and it is thus not surprising that the first effort to apply system dynamics to the Iranian economy was largely ignored.

- **Competing Obligations:** Mashayekhi himself believes[3] that the main reason his model has failed to make a significant impact on Iranian policy making is that his graduation from MIT and return to Iran coincided with the rise of the Islamic regime and the new government asking him to help reconstruct the Iranian higher education system. As such, he was left with little time to publish, promote and extend his model.

Despite these set-backs, the M-Model has the potential to be updated and used for energy-economy analysis in Iran. By reintroducing the M-model, top-level Iranian political and economic decision makers can be reminded that oil dependency can be a potential danger to the long-term economic growth and stability of the country. Moreover, the model can provide a foundation and road map for additional system dynamics modeling projects in the Iranian energy-economy space. Finally, this chapter will show how system dynamics models can be updated and expanded, which is a very important, yet often neglected, part of the system dynamics modeling process. To achieve these goals, this chapter presents an updated and revalidated version of the M-model. The updating and revalidation process involves three main issues:

- **Improvements in Software:** The M-model was developed in 1978. Since then there have been significant improvements in system dynam-

[3] Telephone interview with Ali Mashayekhi on May 12, 2011.

ics validation methods and software tools. For example, the original M-model was written in DYNAMO which is an obsolete tool for applying modern methods of model validation. For this chapter the M-model was reprogrammed in iThink[4] which offers a wide range of validation and verification options.

- **Structural Changes and Historical Data:** In 1978 Mashayekhi simulated the M-model forward in time to project the implications of various policy choices on the growth and stability of the Iranian economy. In the present day, of course, what was once the future is now the past. As such, it is possible to determine how accurately the M-model predicted the future. Not surprisingly, some inconsistencies between the projections of the M-model and the historical data have been identified. Although, system dynamicists believe that the point-by-point fit of a model to time series data is a weak proof of model validity (Forrester and Senge, 1980; Sterman, 1984; Radzicki, 2004) modelers such as Sterman (1984) argue that it is an important consideration because it builds confidence in the eyes of model users. Hence, in order to increase the M-model's potential for acceptance by Iranian policy makers it will be shown that updating exogenous oil export and price data, along with some structural changes and parameter recalibrations, can significantly improve the model's ability to reproduce the historical behavior of the Iranian economy.

- **Model Revalidation and Publication:** Mashayekhi never published a comprehensive analysis of his model's ability to pass a traditional list of tests necessary to build confidence in a system dynamics model (Peterson, 1980). This was probably due to software and/or time limitations, and/or to the level of knowledge of Iranian academics about the system dynamics methodology at that time. As a consequence, revalidating the model and publishing its results will potentially increase its creditability among those economists who insist that valid models require the application of statistical techniques to numerical data.

In the next section a revalidation of the M-model according to criteria that are standard in the field of system dynamics (Sterman, 2000, ch. 21) will be presented.

1.2 Revalidating the M-model

In the field of system dynamics, models are never considered to be purely "valid" or "invalid." Instead, they are evaluated according to their ability to generate confidence in their users. A model never can be validated absolutely because all models are wrong. All models are simplified and abstract versions of real systems. So they can never be regarded exactly as corresponding real systems. So, why do we look for validating a model? The answer is that you, as a leader,

[4] iThink Analyst v9.1.4, 1985-2010.

have to use a model to make your decisions. You may use only your mental models or a mathematical one, etc. Whatever you use, the question is which model you want to use; not whether you can use a model or not (Sterman, 1991, 2000, 2002) Indeed, putting a model through a validation process helps decision makers feel confident that the results they are seeing are legitimate and useful.

Over the years system dynamicists have assembled a comprehensive list of tests to which a model can be subjected in an effort to build confidence among its users[5]. These tests include:

- Boundary adequacy tests
- Structure assessment tests
- Dimensional consistency
- Parameter assessment
- Extreme condition tests
- Integration error tests
- Behavior reproduction tests
- Behavior anomaly tests
- Family member tests
- Surprise behavior tests
- Sensitivity analysis
- System improvement tests

The application of these tests to the M-model will now be described.

1.2.1 Boundary adequacy tests

A model's boundary defines what is included in and excluded from its structure. Boundary adequacy tests evaluate the appropriateness of a model's boundary vis-a-vis the purpose for which it was created. Fig. 1.2.1 presents a sector-level view of the structure of the M-model. It consists of 325 variables and constants embodied in 12 interacting subsystems of the Iranian socioeconomic system.

In addition, Table 1.2.1 lists some important macroeconomic variables that are endogenous, exogenous, and excluded from the M-model. The relevant question is whether or not this structure is still adequate for the M-model's purpose.

The endogenous variables can be examined first. Since the purpose of the M-model is to analyze the effect of oil revenue on the Iranian economy, it makes

[5]See e.g. Forrester (1973); Peterson (1975, 1980); Mass and Senge (1978); Forrester and Senge (1980); Sterman (1984); Barlas (1996); Oliva (2003); Radzicki (2004).

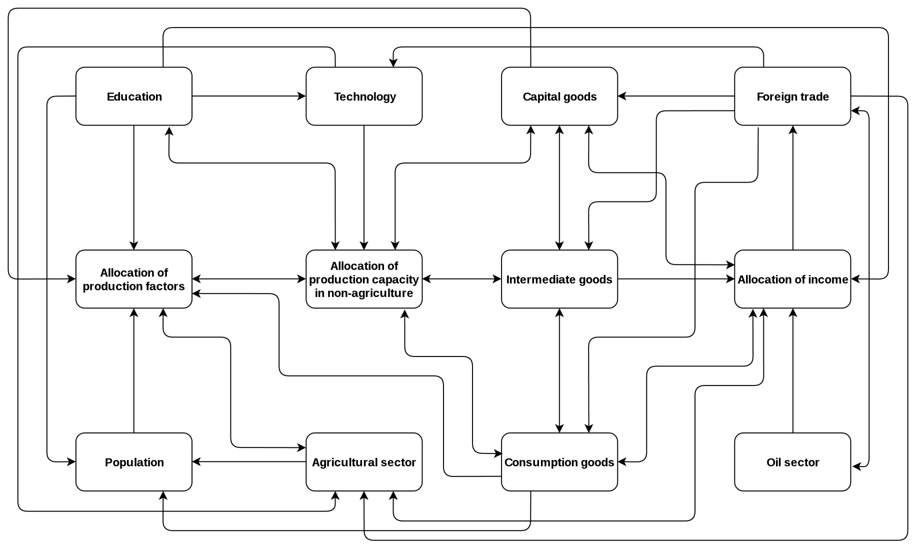

Figure 1.2.1: Sector-level view of the structure of the M-model

Table 1.2.1: List of endogenous, exogenous, and excluded variables of M-model

Endogenous	Exogenous	Excluded
GNP	Labor Market	Oil Imports
Population	Oil Exports	Financial Market
Education	Oil Prices	Exchange Market
Capital Accumulation		Alternative Energies
Energy Consumption		
Foreign Trade		
Technology		

perfect sense to have it calculate a major economic summary index such as GNP. Furthermore, to replicate the dynamics of the aggregate production process in Iran, it is crucial to model population (as generator of the labor force), education (as an important input into the aggregate production function), capital accumulation (as the process that generates capital, which is another important production factor), and technology (again, an important input into the aggregate production function) as endogenous processes. Energy consumption is represented endogenously because it is a process that can limit oil exports and thus Iranian oil revenue. Finally, foreign trade is modeled as an endogenous process in order to capture the dynamics that drive the importation of intermediate goods and to show how foreign exchange is utilized.

In terms of exogenous variables, the dynamics of the labor market in the M-model are represented autonomously. More specifically, the model simply assumes that 56% of the adult population is employed every year. This assumption is employed in order to avoid the complexity of the Iranian labor market. Since the main goal of the M-model is to reproduce the dynamics of Iranian oil dependency, it appears that this simplification is reasonable. Although including labor market dynamics can enhance the M-model's capacity to analyze a wider range of policies and scenarios, this capability is outside the focus of both the original, and present, studies. If the social consequences of oil dependency were the focus of the M-model, then a more sophisticated representation of the labor market would be required. Oil exports are also largely determined exogenously. More precisely, they are set to their historical value for the years 1959–1978 and then determined endogenously thereafter. This is arguably a weakness in the original formulation of the M-model as oil exports are a key factor in generating the model's internal dynamics. The good news is that this problem can be eliminated by adding a comprehensive energy sector to the original M-model[6]. Oil prices are also represented exogenously in the M-model. As with oil exports, the price of oil is set to its historical value for the years 1959–1978. However, unlike oil exports the price of oil is held constant from 1979 to the end of each simulation. Although different assumptions about the price of oil from 1979 forward can be tested, a superior formulation would generate oil prices endogenously because they are a major determinant of oil revenue.

The M-model's endogenous and exogenous variables represent factors that are part of its structure and are thus inside of its boundary. On the other hand, there are some important variables that are entirely excluded from the M-model's structure and hence lie outside of its boundary. For instance, the M-model assumes that the importation of oil to Iran is not possible. This assumption is both a boundary inadequacy and a structural deficiency. It implies that the Iranian economy has no source for oil other than its domestic supply. Of course, this is not true and when domestic oil resources decline significantly Iran will have to begin importing oil. Unfortunately, this scenario is impossible

[6]This has been done by Langarudi et al. (2011).

to be generated in the original formulation of the M-model[7]. Langarudi et al. (2011), nonetheless, present a remedy for this deficiency. Financial and exchange markets are also excluded from the original version of the M-model. These exclusions have reduced the model's ability to fully analyze the impact of oil revenue on the Iranian economy. For example, the dynamics of the so-called "Dutch disease" cannot be explored. An economy afflicted with the Dutch disease experiences an appreciation in real exchange rates due to an unexpected increase in foreign exchange revenue generated by its natural resource exports. This in turn causes a fall in total output and employment in the nonnatural resource sectors (usually the manufacturing sector) as the stronger domestic currency makes nonnatural resource exports relatively more (van Wijnbergen, 1984). Although this is clearly an issue with the boundary of the M-model, this chapter will demonstrate that it still provides an excellent foundation for a more complete model that can be used to analyze a wide range of Iranian macroeconomic issues. Finally, another significant deficiency of the M-model's structure is its reliance on a single energy resource, that is oil. It can be argued, however, that this assumption poses no significant threat to the model's results because it was not designed to analyze the impact of competing energy resources. Nevertheless, adding alternative energy sources to the M-model, in particular natural gas, can certainly improve its usefulness for strategic planning in the energy sector[8].

In sum, the M-model's boundary is somewhat inadequate for the purpose for which it was built. To better study the effects of oil revenue on the Iranian economy, the M-model's boundary must be expanded to include a financial market, an exchange market, an energy market, and the process of energy production. As these improvements are possible, the M-model is arguably still an appropriate base platform for undertaking Iranian socioeconomic analysis.

1.2.2 Structure assessment tests

Structure assessment tests check to see if a model is consistent with knowledge of the real system that is relevant to the purpose for which the model was created. These tests are concerned with the level of aggregation in a model, the fidelity of the model to basic physical facts, and the realism of the decision rules utilized by the agents in the model. Structure assessment tests were performed in all steps of reviewing, recalibrating, and analyzing the M-model[9]. The result of this assessment is that, although the M-model has no egregious structural deficiencies, it contains two structural imperfections. These imperfections will be addressed after a detailed review of the M-model's general structure.

[7] Mashayekhi employed this assumption because the simulation period for the original M-model was 50 years and during this period domestic energy resources were sufficient for domestic energy consumption (see Footnote 11).

[8] Langarudi et al. (2011) have also addressed this issue.

[9] For a comprehensive description of the model's structure see Mashayekhi (1978).

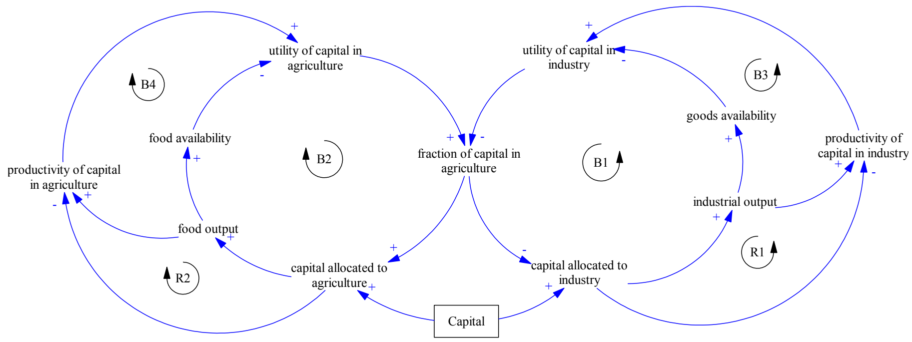

Figure 1.2.2: Resource allocation mechanism of M-model

Resource allocation mechanism

The M-model's agricultural and nonagricultural production processes utilize three inputs: capital, labor, and education. Capital is calculated by accumulating investment in both machinery and construction, and then adding-in the flow of imported capital goods. Labor is supplied by the population sector while education is represented by the average number of years an Iranian citizen spends in school. These three production factors are allocated between the M-model's two production sectors: agricultural and nonagricultural (industrial) sectors. The resource allocation mechanism is based on the relative productivity of the three factors of production and the availability of each sector's output. The availability of a sector's output is a measure of demand relative to supply. To illustrate how this mechanism works in the M-model, Fig. 1.2.2 presents a causal loop diagram of the process[10]. The allocation mechanisms for the other factors of production (labor and education) have the same structure.

Agricultural sector

The model agricultural sector supplies the food demanded by the population. The production function in this sector utilizes the factors of production allocated to it, as well as available farmland and the sector's level of technology. The most important interactions between food production and the rest of the model are shown in Fig. 1.2.3.

Allocation of Production Capacity in the Nonagricultural Sector

Similar to the agricultural sector, a unique production function determines the total production capacity of the industrial (i.e. nonagricultural) sector. This production function utilizes the factors of production allocated to it, as well as

[10] A causal loop diagram presents only the essential feedback structure of a system dynamics model so that the most important elements of cause and effect can be examined. The actual resource allocation mechanism in the M-model is substantially more sophisticated.

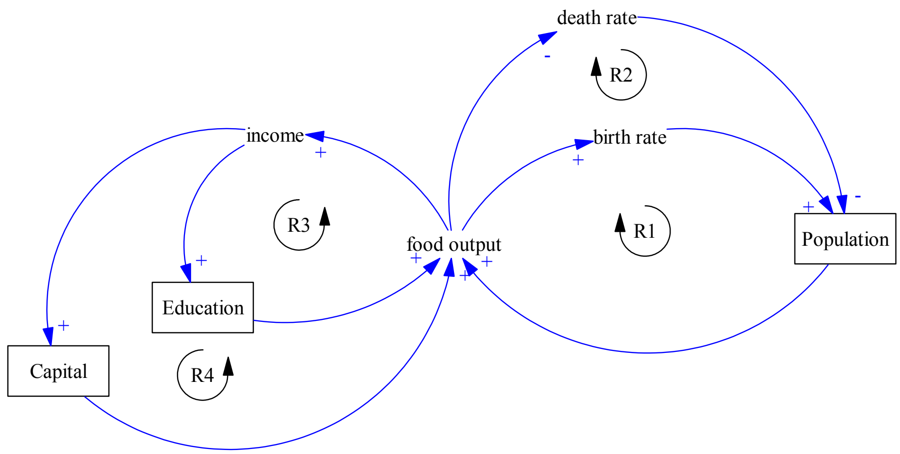

Figure 1.2.3: Food production system of M-model

the sector's level of technology. The total production capacity of the sector is allocated among four competing demands: capital goods production, intermediate goods production, consumption goods production, and educational capacity. Fig. 1.2.4 presents a causal loop diagram of the major processes that determine how the M-model allocates its nonagricultural (industrial) production capacity to consumption goods production. From an examination of the figure it is clear that the production capacity allocated to consumption goods depends on the total production capacity in the nonagricultural sector, the relative productivity of the production factors in consumption goods, the availability of consumption goods, and the availability of intermediate goods. Similar interactions are used to allocate production capacity to the production of capital goods, the production of intermediate goods, and educational capacity.

Education sector

The output of the education sector is people possessing person-years of schooling. Educational output increases when the M-model's education production capacity and the demand for utilizing this capacity, increase. Educational production capacity depends on the demand for education and government policies. The demand for education is a direct function of both personal income and the educational level of Iranian adults. Fig. 1.2.5 shows the aggregate causal relationships in this sector.

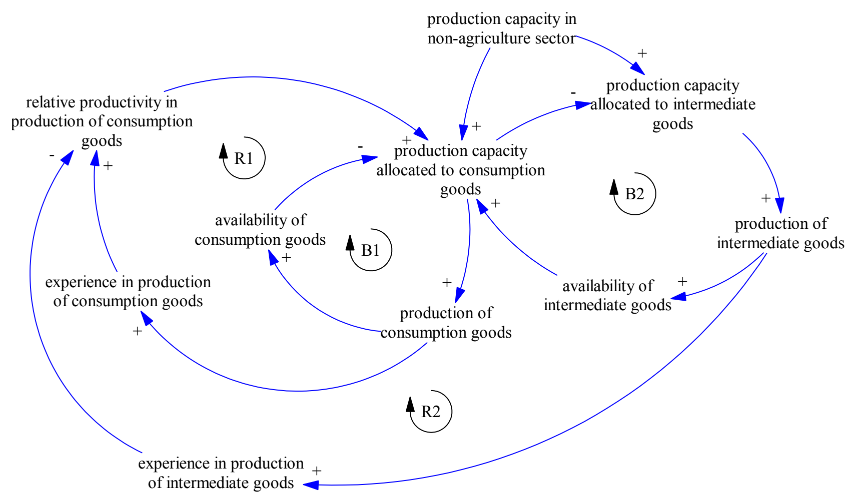

Figure 1.2.4: Resource allocation mechanism for consumption goods of M-model

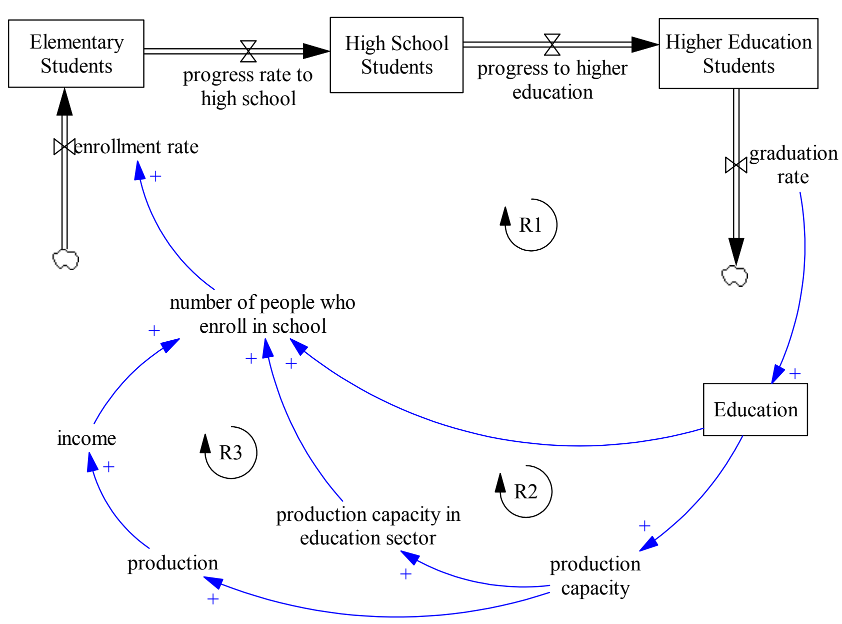

Figure 1.2.5: Education sector of M-model

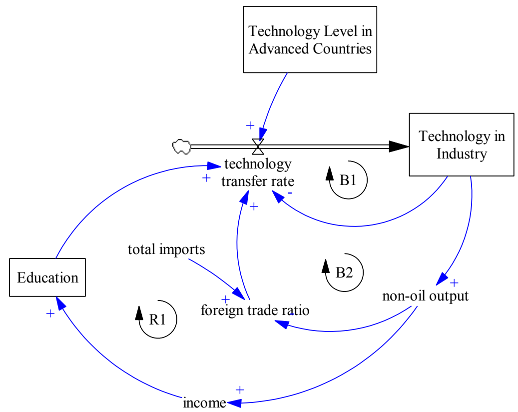

Figure 1.2.6: Technology transfer in the industrial sector of M-model

Technology sector

The technology sector determines how technical progress diffuses into the Iranian economy. The M-model assumes that technical progress depends on technology transfer from developed countries. The transfer rate is determined by two factors: (1) the availability of required technologies that have not yet been transferred to Iran (i.e., the difference between the technology level in advanced countries and the corresponding technology level in Iran) and (2) Iran's ability to transfer technologies. Iran's ability to transfer technology depends on the education level of its work force and its level of foreign trade with developed countries. Fig. 1.2.6 illustrates this mechanism for the industrial sector. Technical progress in the agricultural sector has a similar structure.

Allocation of income

The allocation of income sector determines the allocation of Iranian national income among five competing demands: expenditures on (1) consumption goods, (2) services, (3) food, (4) saving, and (5) investment. The structure of this sector is based on standard microeconomic theory which specifies that the income elasticity of the demand for food and consumption goods is lower than the income elasticity of investment and saving.

Foreign trade sector

Any discrepancy between supply and demand in different sectors of the M-model is addressed through foreign trade. A demand surplus would be imported and a supply surplus would be exported. Imports and exports are also restricted by the availability of foreign exchange and government policies. Fig. 1.2.7 depicts the feedback structure that determines Iranian foreign trade in consumption

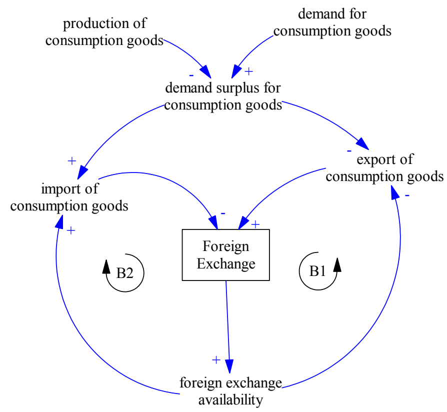

Figure 1.2.7: Trade of consumption goods of M-model

goods. The M-model utilizes the same structure to generate the dynamics of Iranian foreign trade in food, capital goods, and intermediate goods.

Oil sector

In the oil sector, oil is produced and exported to provide Iran with the foreign exchange it needs for its imports. This sector also computes Iran's domestic energy consumption. The feedback structure of the oil sector is shown in Fig. 1.2.8.

Population sector

The population sector of the M-model supplies both the workforce for the economy's production sectors and the consumers of the output from the production sectors. The Iranian birth rate depends on the adult population, available food per capita, the level of Iranian industrialization, and the level of Iranian education. Similarly, the Iranian death rate depends on available food per capita and the level of industrialization. Figures 1.2.9 and 1.2.10 show the feedback structure of this sector.

Minor Structural Imperfections in the M-Model

Although the overall structure of the M-model is excellent, there are two areas in which it is deficient. The first involves oil production; more specifically, oil production in the original version of the M-model can be doubled in just 1 year. Although this assumption might have been reasonable for the period before the Islamic revolution of 1979, when the Iranian state was able to attract as much foreign investment as it needed due to its good relationship with the developed

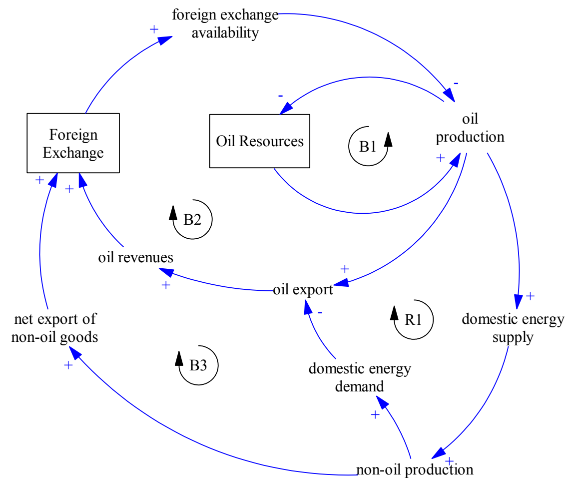

Figure 1.2.8: Oil sector of M-model

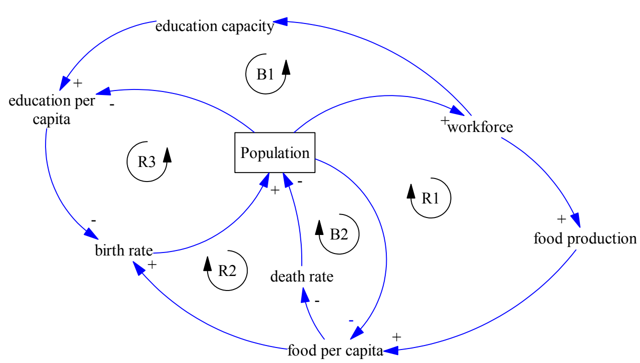

Figure 1.2.9: Population sector of M-model (Part 1)

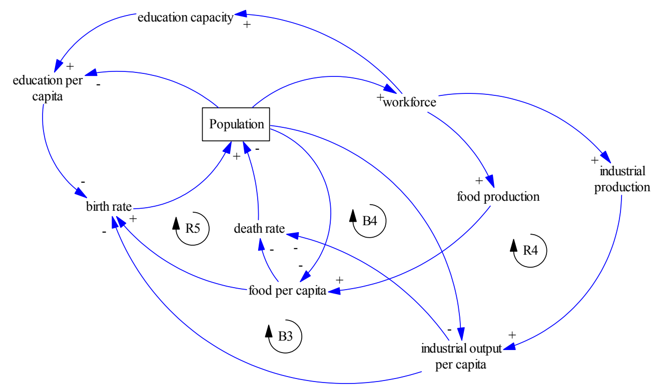

Figure 1.2.10: Population sector of M-model (Part 2)

world, it is not a valid assumption for the postrevolution era. Indeed, after the 1979 revolution the Iranian government could not persuade major oil companies to invest in its oil and gas industry (Katouzian, 2009).

The second area in which the structure of the original M-model is deficient involves energy supply. The original model assumes that there is only one source of Iranian energy—domestic oil production. This assumption implies that the importation of energy is impossible. Even if the domestic supply of energy is sufficient for domestic energy demand, this assumption weakens the robustness of the M-model vis-a-vis extreme conditions. In other words, good system dynamics modeling practice requires that a model behaves correctly under extreme conditions, even if those conditions have never occurred in the actual system and/or will only occur in the model under extreme circumstances. If a simulation run of the M-model depletes all Iranian energy resources, the economy still survives. Of course, this is extremely unrealistic. Mashayekhi (1978) argues that people will use wood when oil resources are scarce and the M-model implicitly assumes that burning wood is costless—which is simply not true. Despite these criticisms, available energy data shows that the net export of energy for Iran will be positive for at least next eight decades[11]. As a consequence, the structure of the M-model can be said to be adequate in simulation runs shorter than fifty years in duration.

1.2.3 Dimensional consistency

Good system dynamics modeling practice requires that all of a model's equations be dimensionally consistent. This means that all of a model's equations

[11]Simulations by Langarudi et al. (2011) show that Iran's net export of energy won't become negative until 2094. This result is yielded under this assumption that world demand for Iran's oil is infinitive so Iran can export that portion of its produced oil remaining after domestic consumption.

must produce stocks that are measured in "units" and flows that are measured in "units/time." All of the equations in the M-model were checked and no dimensional inconsistencies were found.

1.2.4 Parameter assessment

The parameter assessment test determines whether a model's parameter values are consistent with relevant descriptive and numerical knowledge of the actual system, and whether all the model's parameters have real world counterparts. To answer these questions, all parameters of the model were checked and no inconsistencies were found among them and their real world counterparts. Mashayekhi's dissertation presents a comprehensive documentation of the M-model's parameters and how they were obtained.

1.2.5 Extreme condition tests

Tests of extreme conditions are designed to evaluate whether or not each equation in a model makes sense when its inputs take on extreme values. In other words, they test whether or not a model's equations respond reasonably when subjected to extreme policies, shocks, and parameters. To test the M-model for extreme conditions, each equation was evaluated, in isolation, for its response to extreme values for each of its inputs, alone and in combination. In addition, the overall M-model was subjected to large shocks and extreme conditions and then inspected for conformance to basic physical laws (e.g. an absence of inventory should mean there will be no shipments; zero labor should mean zero production). All these tests revealed no serious problems with the M-model. However, some minor defects were detected. For example, the birth rate in the population sector was set to zero for all years after 2000. The result is shown in Fig. 1.2.11. The Iranian population should have reached to zero in approximately 150 years. However, Fig. 1.2.11 shows that the population is still positive at year 2700. This implies that there are some individuals who can live for more than 700 years! This is a common problem that arises from high level of aggregation in population modeling and could be resolved by employing specific programming techniques (Eberlein and Thompson, 2013). The good news is that this deficiency does not significantly influence the primary results of the M-model and it can be corrected in a future version of the model.

1.2.6 Integration error tests

System dynamics models are continuous time models run on discrete machines (digital computers) and are thus solved via numerical integration. As a result, modelers must choose both a numerical integration method, and a time step, to approximate the continuous dynamics of the underlying system. Too large a time step utilized in concert with a particular numerical integration technique may yield too much integration error and thus simulated time paths

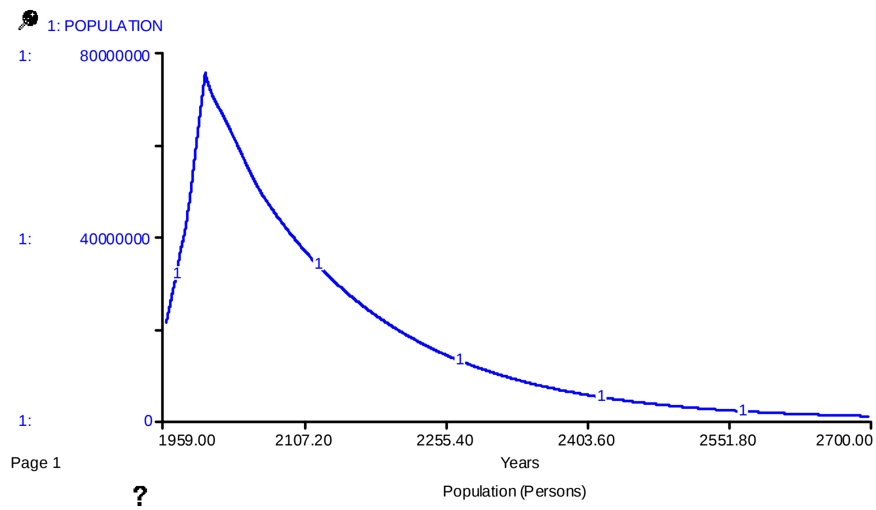

Figure 1.2.11: Iranian population when the birth rate is set to zero after the year 2000

that are too inaccurate for the problem at hand. Too small a time step utilized in concert with a particular numerical integration technique may yield simulated time paths that are unnecessarily precise for the problem at hand and thus simulation runs that are needlessly computationally intensive (i.e., slow)[12]. Good system dynamics modeling practice, therefore, requires picking a time step/numerical integration combination that is no more accurate than is necessary for the problem at hand. This is typically accomplished by selecting an initial time step/numerical integration technique combination, running the model, cutting the time step in half, rerunning the model, and inspecting the pre- and post-cut synthetic time paths for significant differences. When no significant differences in dynamic behavior can be detected, the model is deemed to be accurate enough for the problem at hand[13].

The M-model was systematically tested with different numerical integration methods and time steps[14]. Euler's method (the default simulation method in most system dynamics modeling packages due to its simplicity and computational ease) proved to be fine and a time step reduction to 0.1 year yielded no significant change in model behavior.

[12] In the extreme, the smallness of a model's time step is limited by the precision of the digital computer being used.

[13] Mathematical rules of thumb relating a model's time step to its smallest time constant also exist in system dynamics modeling.

[14] Various numerical integration techniques have well-known strengths and weaknesses that come into play under different circumstances.

1.2.7 Behavior reproduction tests

Many system dynamicists believe that historical fit is a weak test for model validity (Forrester, 1973; Forrester and Senge, 1980; Sterman, 1984; Radzicki, 2004). As (Forrester, 2003, p. 5) has written:

> There is no reason that a generic model should reproduce any specific historical time series. Instead, it should generate the kind of dynamic behavior that is observed in the systems that are being represented. If one runs the model with different noise sequences one will get simulations that have the same character, but not the same values at different points in time. Likewise, the time series from an actual economy represent only one of a multitude of detailed behaviors that might have occurred if the random effects in the real system had been different. In other words, historical data from a real economy should be interpreted as only one of a multitude of possible data histories.

The consensus view in the field of system dynamics is that, although reproducing historical behavior is only one of many tests required to build confidence in a system dynamics model, it can often be essential. Failure to convince a reviewer that a model's historical fit is satisfactory, for example, is often sufficient grounds for him/her to dismiss the model and its conclusions (Sterman, 1984).

Sterman (1984) lays out a detailed example of how Theil's inequality statistics (Theil et al., 1966) can be used to analyze the fit of a system dynamics model to historical data. These statistics are used in this chapter to examine the fit of the modified M-model to historical data from Iran. Before applying these statistics, however, the structural deficiencies of the M-model must be addressed and its behavior updated. The first step in this process is to update the M-model's exogenous variables with the latest available data. Recall that the major exogenous variables in the M-model are oil exports and oil prices. Utilizing modern data, the initial value of Iranian oil reserves was updated from 100 to 221 billion barrels. Iran's remaining proven reserves at the end of 2011 were estimated to be 154.6 billion barrels (OPEC, 2012). The cumulative production of oil in Iran since 1959—which is the starting date for M-model simulations—until the end of 2011 was about 66.5 billion barrels (OPEC, 2010). This means that Iran should have had 221.1 billion barrels of total proven reserves in 1959 ($154.6 + 66.5 = 221.1$ billion barrels). Of course, alternative values for initial oil reserves also can easily be tested in the model. Fig. 1.2.12 presents a comparison of actual and simulated Iranian non-oil output, from 1959 to 2007, after updating the initial value of Iranian oil reserves in the M-model as described earlier[15]. Other key variables from the M-model were monitored during this recalibration process but are not presented here due to space limitations[16].

[15] All real world data presented in this chapter comes from three main sources: (1) the electronic database of the Central Bank of Iran (CBI, 2012), (2) OPEC Annual Statistical Bulletin (OPEC, 2010, 2012), and (3) the BP Statistical Review of World Energy (BP, 2012).

[16] A summary of the M-model's ability to replicate the dynamics of the key variables in the Iranian economy is presented at the end of this section in Tab. 1.2.1.

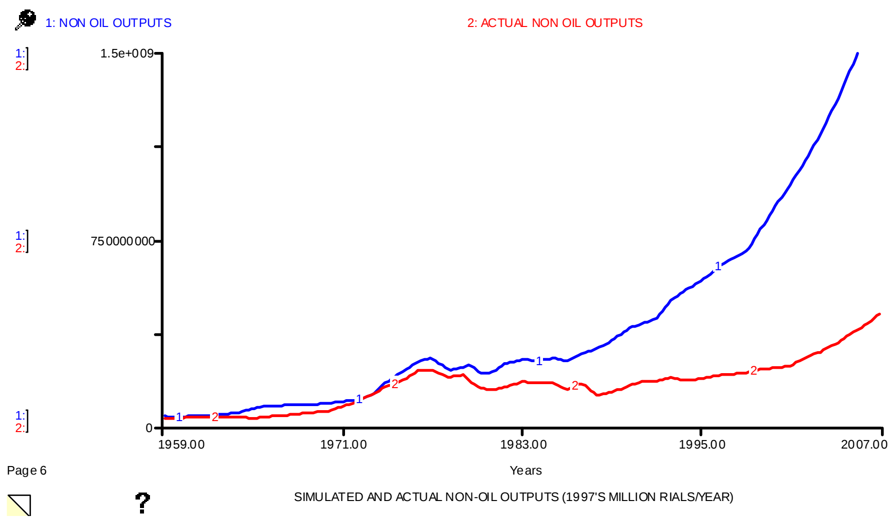

Figure 1.2.12: Actual and simulated non-oil output after updating the initial value of oil reserves

Non-oil output was chosen as a more plausible index of general economic output than GNP because GNP includes oil revenue. Since oil revenue is exogenously determined by a historical time series from 1959 to 2007, a large portion of the M- model's ability to reproduce Iranian GNP would be attributable to an exogenous input. Focusing on non-oil output, on the other hand, can better illustrate the M-model's ability to endogenously replicate the real system's behavior.

Fig. 1.2.12 shows that the updated M-model's qualitative behavior, i.e., exponential growth followed by a peak, a decline, and the resumption of exponential growth, is very close to the real system's behavior. The point-by-point fitness of the M-model, however, is clearly not acceptable. Therefore, it is necessary to review the original assumptions of the M-model and if possible, modify them in order to improve the model's ability to replicate Iranian economic history. The discrepancy between the behavior of the updated M-model and Iranian historical data starts and expands after 1979 when the Islamic revolution took place. As was previously mentioned, the revolution was followed by an eight-year war with Iraq. The most likely cause of the divergence between the actual and synthetic data presented in Fig. 1.2.12, therefore, is these events and the changes they caused in Iranian political economy. To test this hypothesis, structural changes representing the revolution and war must be introduced into the M-model. Katouzian (2003) argues that Iranian society had to endure the following impacts from the revolution and the war beginning in 1979:

- a reduction in oil exports,

- a reduction in the utilization of production capacity in the economy,
- a high rate of capital flight,
- a high rate of brain drain,
- a reduction in the rate of investment, and
- a deep enmity between Iran and Western countries.

Here is an explanation of how these impacts are introduced into the M-model:

- Reduction in oil exports—since oil exports are treated as an exogenous input into the M-model until 2007 no further action is required.

- Reduction in the utilization of production capacity in the economy—to introduce this effect a new variable called the "economic security indicator" (ESI) is introduced into the M-model. This variable is positively influenced by the growth rate of Iranian GNP, but only after a significant asymmetrical delay. More precisely, when the Iranian GNP growth rate increases the ESI increases, and when it decreases the ESI decreases. However, the delay between a change in Iranian GNP and a change in the ESI is longer when GNP is rising compared to when GNP is declining. Changes in the ESI then influence the utilization of production capacity in the economic sectors of the M-model. The rationality behind this assumption is that after the 1979 revolution many business owners left or had to leave the country because they were suspected to be in contact with the dethroned Shah or his family (Katouzian, 2009). In addition, many factories were underutilized due to an economic recession which was the natural result of the 1979 political turmoil and the war with Iraq (Pesaran, 2000).

- High rate of capital flight—to introduce this effect into the M-model, the ESI is also modeled to affect foreign exchange reserves.

- High rate of brain drain—the M-model assumes that a fixed percent of highly educated people emigrate every year from Iran after the 1979 revolution. The percent rate of emigration can be changed by the model user.

- Reduction in the rate of investment—since investment rates in the model are determined by desired investment rates, and desired investment rates are based on the current utilization of a sector's production capacity, the effect of the ESI on the utilization of production capacity automatically adjusts the M-model's investment rates in response to the overall condition of the Iranian economy.

- The enmity between Iran and Western countries—after the 1979 revolution some actions by radical Iranian revolutionists turned the governments of many western nations against the new Iranian state. The response of these governments was to implement political and economic sanctions

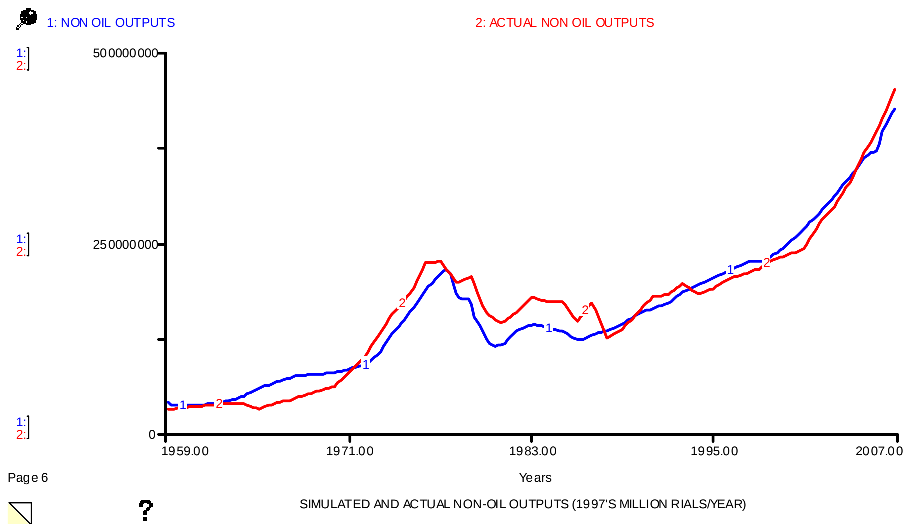

Figure 1.2.13: Actual and simulated non-oil output after introducing the second set of changes

> against Iran. This forced Iran to pay higher prices for imported goods. Another result of this hostility was an increase in the difficulty Iran faced in transferring-in technology from developed countries. These facts are introduced into the M-model by defining a "hostility effect multiplier." This multiplier is an autonomous number between zero to four. When it is zero, it means that there is no hostility effect while "four" represents the highest tension in Iranian foreign relationships. Then, this multiplier affects two variables in the model: it has a negative impact on "technology transfer rate" and a positive impact on the value of "imports" (it increases the import expenses). Users of the M-model can manually change this multiplier to see how it influences the system's dynamics.

Fig. 1.2.13 presents a comparison of actual and simulated Iranian non-oil output, from 1959 to 2007, after the next set of modifications (described earlier) are introduced into the M-model. A quick visual inspection of the figure reveals that the changes have significantly improved the ability of the M-model to reproduce Iranian historical data.

A more rigorous analysis of the ability of the M-model to reproduce historical data from the Iranian economy involves Theil's Inequality Statistics. Tab. 1.2.2 presents the Theil Statistics for four key variables from the M-model. In this table, r represents the correlation coefficient between simulated and actual data; U represents the inequality coefficient and U^M, U^S, and U^C reflect the fraction of the mean square error (MSE) attributable to bias, unequal variance and unequal covariance, respectively.

Table 1.2.2: Theil statistics for key variables after introducing the second set of changes

Variables	r	U	U^M	U^S	U^C
Gross National Product	0.985	0.057	0.192	0.101	0.707
Non-oil outputs	0.979	0.062	0.209	0.161	0.630
Oil production	0.930	0.090	0.175	0.013	0.812
Population	0.996	0.017	0.045	0.019	0.936

Inspection of Tab. 1.2.2 reveals that the correlation coefficient for all four variables is quite high and the inequality coefficient is reasonably low. Moreover, the majority of the MSE for all four variables is concentrated in unequal covariation (U^C). (Sterman, 1984, p. 220) interprets this situation as follows:

> If the majority of the error is concentrated in unequal co-variation U^C , while U^M and U^S are small, it indicates that the point-by-point values of the simulated and actual series do not match even though the model captures the average value and dominant trends in the actual data well. Such a case might indicate a fairly constant phase shift or translation in time of a cyclical mode otherwise reproduced well. More likely, a large U^C indicates one the variables has a large random component or contains cyclical modes not present in the other series. In particular, a large U^C may be due to noise or cyclical modes in the historical data not captured by the model. A large U^C indicates the majority of the error is unsystematic with respect to the purpose of the model, and the model should not be faulted for failing to match the random component of the data.

Therefore, it is reasonable to conclude that the second set of revisions to the M-model enable it to reproduce the actual system's behavior reasonably well. Not only are all the inequality coefficients from the Theil statistics small but most of the errors are unrelated to bias or unequal variance between the simulated and actual data.

1.2.8 Behavior anomaly tests

Data limitations often lead to difficulty in establishing the statistical significance of many relationships in a model. The importance of these relationships can, nevertheless, be examined by "behavior anomaly tests." These tests involve determining whether or not anomalous model behavior arises when a relationship is deleted or modified. Anomalous behavior generated due to the elimination of a relationship would be a sign of the importance of the relationship. Most of the relationships in the M-model were tested and no unnecessary or useless structure was found.

1.2.9 Family member tests

The family member test examines a model's ability to generate the behavior of other cases within the same class as the system being modeled. The greater the number of cases a model can mimic, the more general the theory the model represents. The M-model was developed to address Iranian macroeconomic issues. Iran is an oil-exporting country and is highly dependent on its oil revenue. It also has a relatively large population and a notable agricultural sector with about 16% average share of total GNP value (during 1959–2007) (CBI, 2012). In the real world it is possible to identify clusters of nations that are somewhat similar to Iran. Karl (1997, 1999), for example, argues that Iraq, Nigeria, Algeria, Indonesia, Venezuela, Ecuador, and Mexico possess many common characteristics and refers to them as "capital-deficient" countries. To pass a family member test, the M-model must be able to generate the macroeconomic behavior of at least some of these countries after a reasonable amount of modification to reflect each nation's unique features. Although this sort of effort is beyond the scope of this chapter, it can be argued that the M-model possesses a generic structure that can be applied to all "capital-deficient" countries.

1.2.10 Surprise behavior tests

Inconsistency between a model's behavior and its expected behavior reveals that there are some deficiencies in the formal model, the modeler's "mental model," or both. According to (Sterman, 2000, p. 882):

> Often, of course, discrepancies between model output and our understanding of the system's dynamics indicate flaws in the formal model. Occasionally, however, it is our mental model and our understanding of the data that require revision.

The surprise behavior test is passed when a model generates a certain behavior, previously unrecognized, and it does indeed occur in the real system. To test the M-model for surprise behavior it must be run under a variety of scenarios and its results carefully examined. Fig. 1.2.14 presents a base run for the M-model from 1959 to 2060 after the second set of modifications has been introduced. The synthetic variables presented include: non-oil outputs (million rials per year), disposable income per capita (rials per person per year), food output per capita (rials per person per year), oil reserves (billion barrels), and oil production (million barrels per year).

After the second set of modifications the M-model produces the following behavior from the year 2007 forward. Oil production and oil exports grow exponentially causing Iranian oil reserves to deplete rapidly. The increase in oil exports provides the Iranian government with an influx of foreign exchange. This huge windfall of oil revenue makes it possible for Iran to import the goods it needs. It also improves the people's purchasing power, so the demand for consumption goods rises. The urgent need for an increased supply of consumption

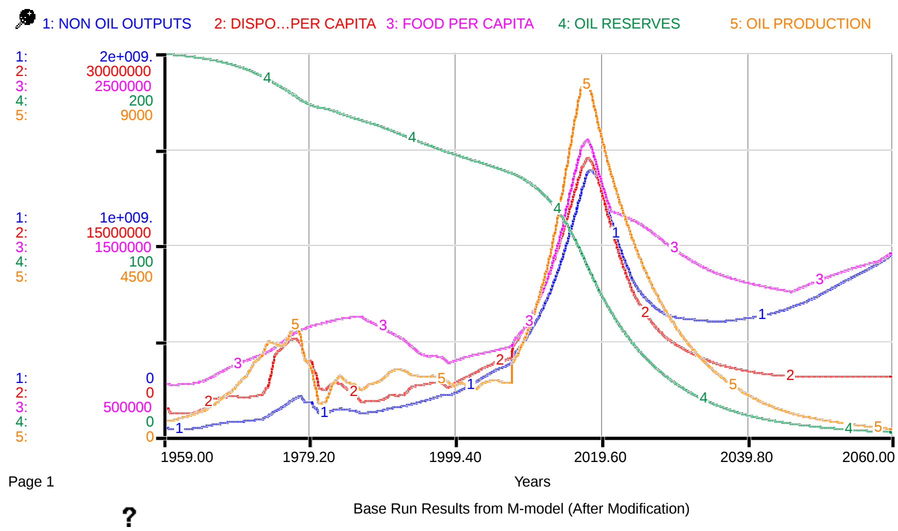

Figure 1.2.14: Base run after the second set of modifications

goods shifts the economy's production factors from its other sectors to the consumption goods sector. As a result, the intermediate goods sector weakens. Of course, the economy needs intermediate goods to keep the production capacity of the consumption goods sector fully utilized. A quick response to this pressure is to import intermediate goods. This would normally address the problem in the short-term. However, over time Iran's oil reserves deplete at a rapid rate causing oil revenue to decrease and the importation of intermediate goods to become limited. Since the economy cannot seamlessly substitute the production capacity of the consumption sector for the production capacity of the capital goods sector, this leads to a severe depression. Stated differently, the depletion of Iranian oil reserves shown in Fig. 1.2.14 occurs so quickly that the economy cannot react to it in a timely fashion.

Even though the modified M-model generates an internally consistent story, some aspects of its behavior are surprising. For example, there is no way that Iranian oil production could expand as quickly as is shown in Fig. 1.2.14. The sharp increase in oil production is related to an unrealistic assumption embedded in the model. More specifically, the M-model assumes that Iran is able to double its oil production in a period as short as 1 year. An examination of the historical data, however, shows that this cannot possibly be true, particularly in the post-revolution era. Fig. 1.2.15 shows the history of changes in Iranian oil production from 1965 to 2011.

From an inspection of the figure it is clear that Iranian oil production has not been able to rise dramatically in any given year since the 1980s. Indeed, the last extraordinary high growth rate (23%) occurred in 1989. Moreover, significant

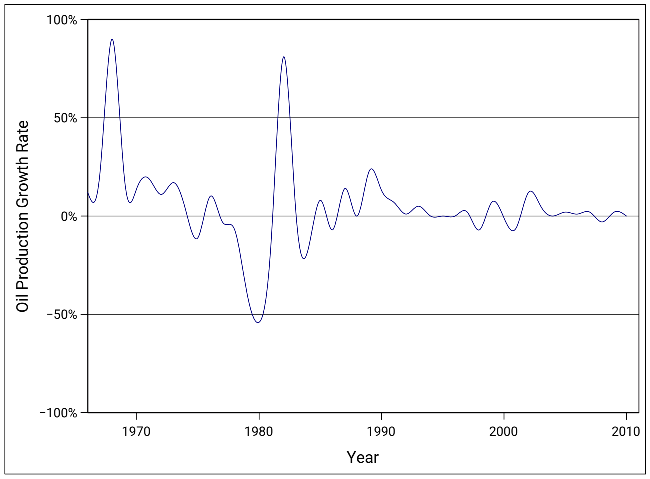

Figure 1.2.15: Historical changes in Iranian oil production (BP, 2012)

increases in oil production appear to occur in years following a deep fall in oil production. This implies that high rates of growth are due to the reutilization of an underutilized existing production capacity, rather than from an increase in overall production capacity. After the 1979 revolution the expansion of Iran's oil production capacity became more difficult because of a dramatic change in the new state's foreign policies that made foreign investment problematic. Energy economists believe that the main contemporary challenge in the Iranian energy sector is the lack of funding and investment (Barkeshli, 2006). It is perhaps reasonable to assume that the pre-revolutionary Iran could double its oil production in 1 year, but it is not a realistic assumption for the post-revolutionary Iran. Clearly, the surprise behavior of the M-model presented in Fig. 1.2.14 reveals a need to further modification of the M-model's structure. The next version of the model assumes that the maximum growth rate of Iranian oil production is 14%[17]. The model is run again and the results are shown in Fig. 1.2.16.

Figure 19 reveals that there is no severe depression in the economy from 2007 to 2060, despite the egregious depletion of Iranian Oil reserves. The reason is that Iranian oil production grows more slowly than in previous versions of the M-model (compare to Fig. 1.2.14) and the model economy, therefore, has enough time to wean itself from oil revenue. In other words, Iran's inability to attract enough investment to develop its oil industry leads to less dependency on oil revenue. In fact, this was a policy originally proposed by Mashayekhi (1978) to alleviate the economic recession he had predicted for the 1990s. He had suggested that the Iranian government could slow down the production of oil as a policy choice so that the economy could adapt to the difficulties that

[17]Except for 1981, the highest growth rate after the revolution is 10.98% in 1988 (BP, 2012).

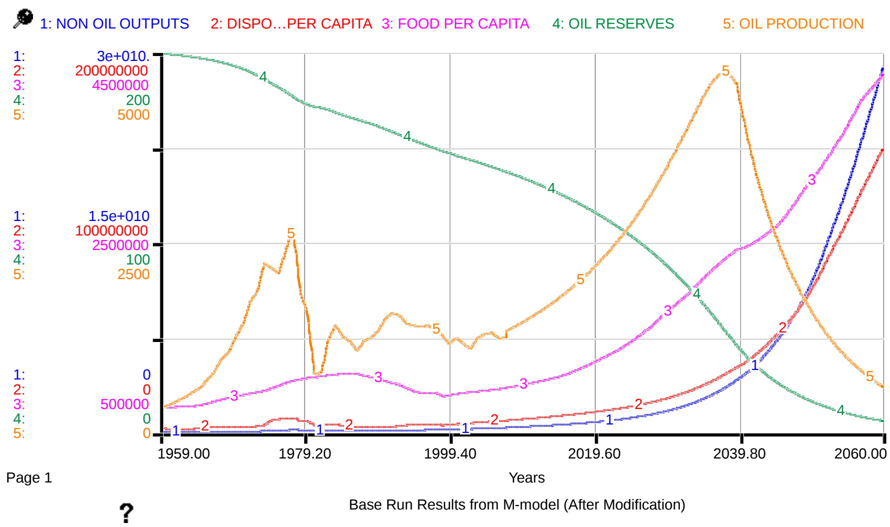

Figure 1.2.16: Base run after the final modification

would arise from the reduction in oil revenue he predicted for the 1990s. In reality, the 1979 revolution and war with Iraq forced Iran to slow down the production of oil. But, regardless of whether the slowdown was voluntary or mandatory its results are consistent with Mashayekhi's prediction.

1.2.11 Sensitivity analysis

Sensitivity analysis reveals the robustness of a model's results with respect to changes in the values of its parameters over a reasonable range of uncertainty. There are three types of model sensitivity: "numerical," "behavior mode," and "policy." A model is numerically sensitive when a change in the values of its parameters changes the numerical values associated with its behavior. Of course, no mathematical model can be perfectly numerically insensitive. A model is behaviorally sensitive when the patterns of behavior it generates change with a change in the values of its parameters. For instance, a model would demonstrate behavior mode sensitivity if reasonable alternative parameter values changed its behavior from, say, overshoot and collapse to S-shaped growth. Policy sensitivity exists when the impact or suitability of a suggested policy change is significantly altered by a change in the values of a model's parameters. Since the purpose of the M-model is to determine whether or not Iran will experience economic growth during its transition from an oil-rich to an oil-poor nation, the focus of this section will be on behavior mode and policy sensitivity.

Behavior mode sensitivity

The behavioral sensitivity of the modified M-model will be reported in this section. To conduct the test, the values of important parameters in the M-model were systematically varied over a range of uncertainty and an examination of how the M-model's behavior changed in response was conducted. "Disposable income per capita" is chosen as the proxy for the model's overall behavior and as an example of the test[18]. Each of the parameter values was randomly altered twenty times over a range of ±50% of their base case values, using a uniform probability distribution. The overall results of the behavior mode sensitivity test showed that, generally speaking, the modified M-model's behavior is not sensitive to changes in its parameters. However, a few parameters did prove to be more influential than others. The sensitivity test for five of the model's parameters is shown later.

Consider the modified M-model's two Cobb–Douglas production functions—one for the industrial sector and the other for the agricultural sector. Sensitivity testing revealed that the model is numerically very sensitive to the elasticity parameters for the inputs to the two functions. For example, Fig. 1.2.17 presents the sensitivity of the modified M-model to changes in "exponent of labor in agricultural sector production function" (ELA). The base value of this parameter is 0.45 and the range for the sensitivity test was 0.225–0.675. Although the modified M-model is numerically very sensitive to the value of ELA, its behavior mode does not change significantly. Sensitivity analysis for the parameters of the other production function in the modified M-model yields similar results.

The next parameter examined is "fraction of investment in capital equipment" ($FICE$). This parameter determines the portion of domestic demand that is allocated to capital goods production and the portion that is allocated to construction. The base value for $FICE$ is set to 0.317 and the range for the sensitivity test was 0.158–0.475. Fig. 1.2.18 presents the results. From a visual inspection of the figure, it is obvious that the M-model's behavior is not sensitive to the changes in $FICE$.

Another parameter which was selected for examination is "normal reserve coverage time" (NRC). This parameter determines how quickly the government depletes Iranian oil reserves. The base value for this parameter is set to 15 years. This means that the Iranian government adjusts its oil production rate such that existing oil reserves will last 15 more years. The range of values for the sensitivity test was chosen to be between 8 and 22 years. The results of the test are shown in Fig. 1.2.19. Again, from a visual inspection of the figure, it is obvious that the modified M-model's behavior is insensitive to changes in NRC.

The next parameter selected for presentation is "normal industrial output per capita" ($NIPC$). In the population sector, the birth and death rates depend on the level of industrialization in the country. $NIPC$ provides a base value against which industrial output per capita generated by the model can be

[18] The behavior of all of the M-model's key variables was examined during the behavior mode sensitivity test but space limitations prevent their presentation in this chapter.

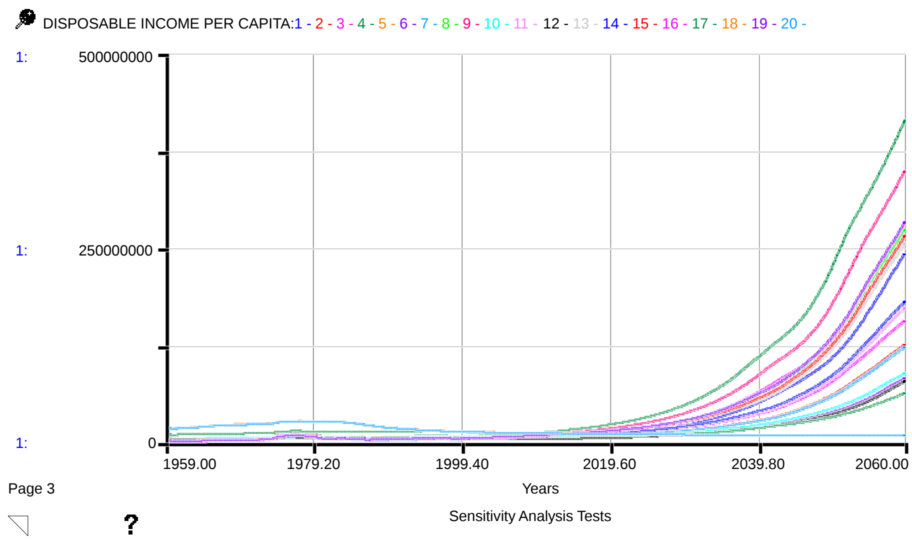

Figure 1.2.17: Behavioral sensitivity of disposable income per capita in the modified M-model to changes in *ELA*

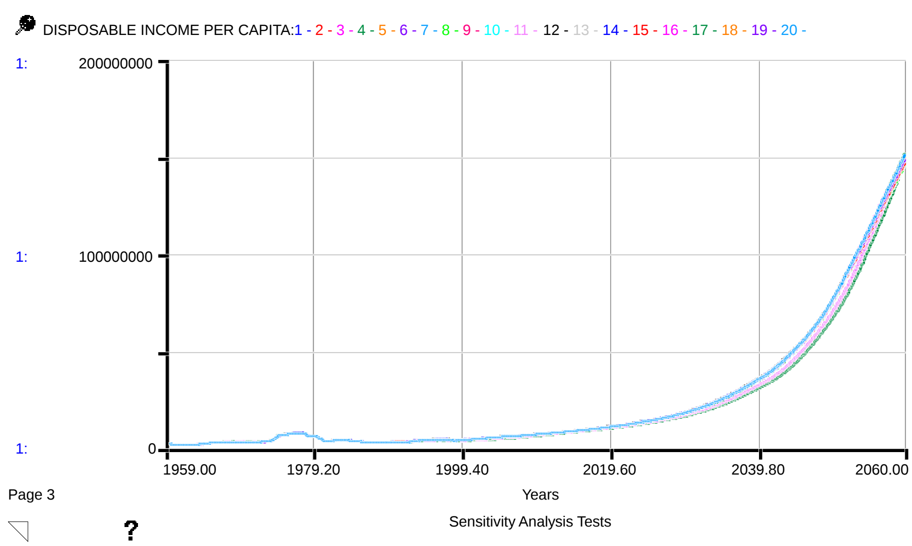

Figure 1.2.18: Behavioral sensitivity of disposable income per capita in the modified M-model to changes in *FICE*

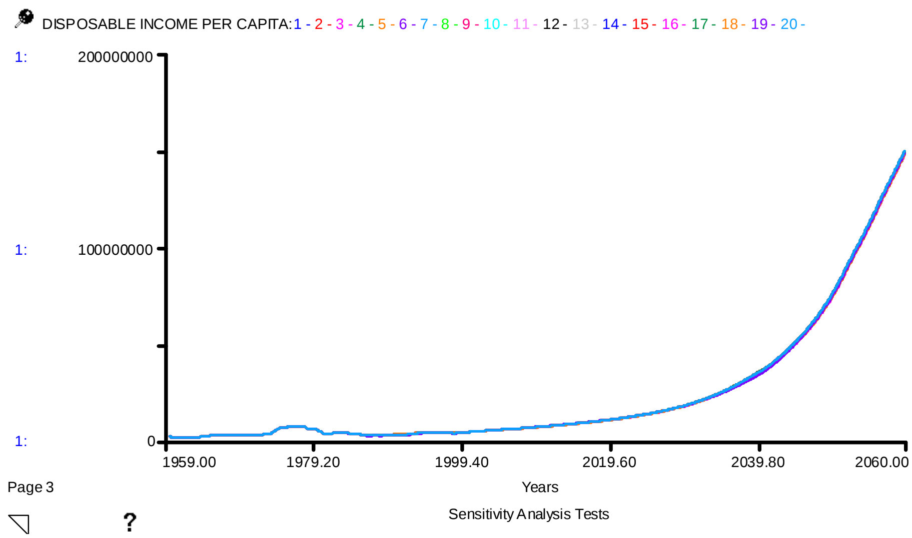

Figure 1.2.19: Behavioral sensitivity of disposable income per capita in the modified M-model to changes in NRC

compared. This comparison provides an indication of the rate of Iranian industrialization. The base value of $NIPC$ is 1,015,272 rials and the range of its value during the sensitivity test is 507,636–1,522,908 rials. Fig. 1.2.20 presents the results of the test. Once again there is no evidence that the modified M-model is behaviorally sensitive to changes in $NIPC$.

The next test of model sensitivity involves the parameter “non-oil output per capita normal” ($NOOPCN$), which provides a base value against which non-oil output per capita ($NOOPC$) can be compared. If the ratio of $NOOPC$ to $NOOPCN$ is greater than 1 Iranian education capacity expands. Alternatively, if the ratio is less than 1 Iranian education capacity shrinks. The default value of $NOOPCN$ is 3,555,739 rials per year per person ($RPYPP$) and the range of values explored during the sensitivity test is 1,777,870–5,333,608 $RPYPP$. The results of the sensitivity test are shown in Fig. 1.2.21. Clearly, the behavior of the modified M-model is insensitive to this parameter.

For the last example presented in this chapter, all five of the parameters discussed earlier are varied simultaneously. Fig. 1.2.22 shows that the modified M-model is numerically sensitive, but behaviorally insensitive, to the combined set of changes. Indeed, all but one of the simulation runs generates exponential growth in disposable income per capita.

Policy sensitivity

If decision makers are to have confidence that the policy prescriptions generated by a system dynamics model are likely to yield the same results in the

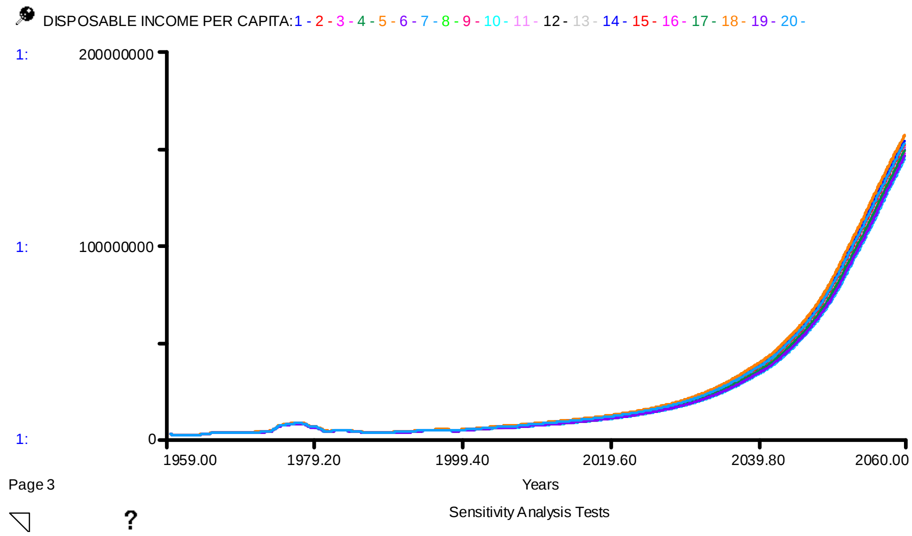

Figure 1.2.20: Behavioral sensitivity of disposable income per capita in the modified M-model to changes in *NIPC*

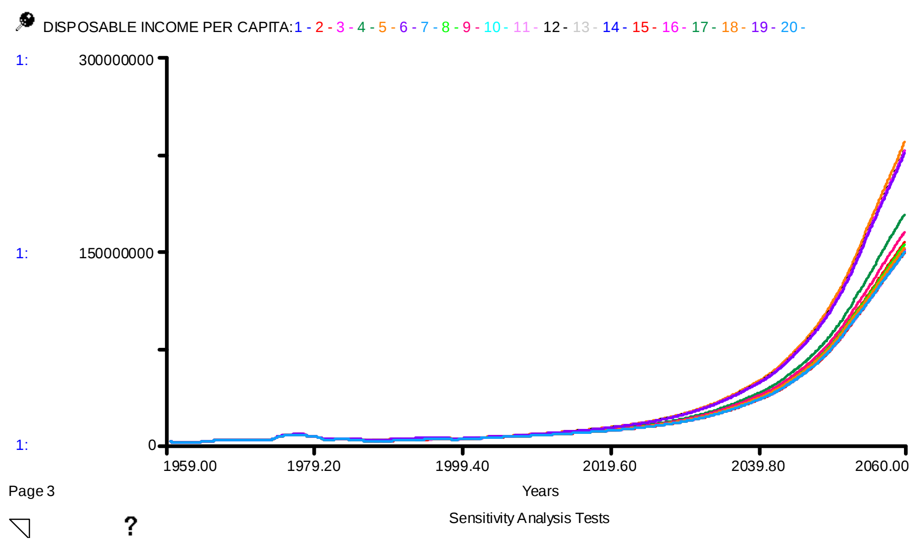

Figure 1.2.21: Behavioral sensitivity of disposable income per capita in the modified M-model to changes in *NOOPCN*

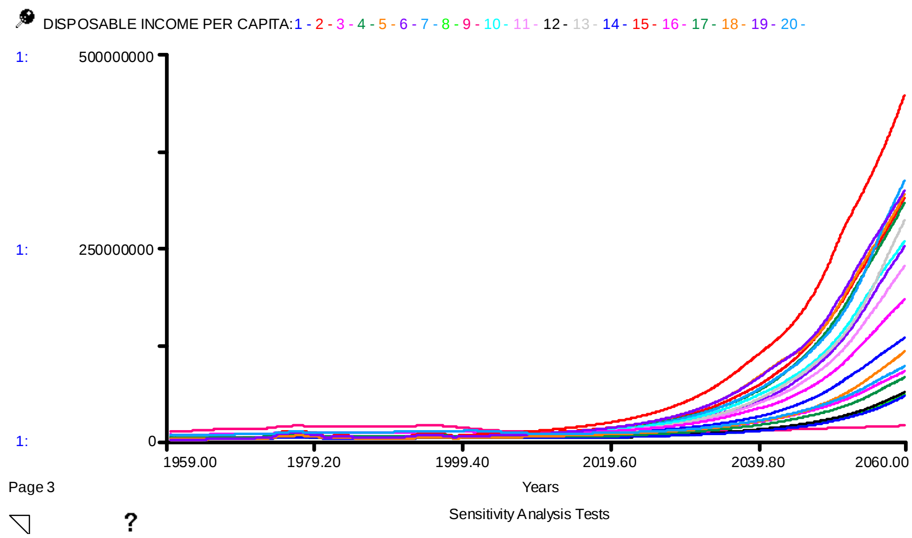

Figure 1.2.22: Behavioral sensitivity of disposable income per capita in the modified M-model to simultaneous changes in all five parameters

real system as they do in the virtual world, the policy prescriptions have to be robust. That is, the policy prescriptions should not change when a model's parameters are varied over a reasonable range of values. This section will present the results of policy sensitivity tests run on the modified M-model. As a prerequisite, however, some policy conclusions need to be drawn from the model. Recall that, although the M-model has the potential to be a foundational platform for Iranian macroeconomic modeling, its current structure is quite limited. More specifically, its current structure is appropriate for examining issues related to the oil dependency of the Iranian economy, but not for answering broader macroeconomic questions in the areas of fiscal, monetary, or income redistribution policies. Recall also that one of the counterintuitive conclusions drawn from simulations of the M-model is that slowing down or limiting investment in Iranian energy production will yield long-term benefits for the economy. This conclusion is in sharp contrast to the viewpoint held by many energy experts who believe that the Iranian government should attract more investment to speed-up Iranian oil and gas production (Barkeshli, 2006).

The "more investment now" viewpoint is principally based on two perceptions. First, most of Iran's proven oil reserves are in the second half of their life cycles (MOE, 2008). As a result, if secondary or tertiary oil recovery methods are not brought on-line, it will become increasingly difficult to exploit these reserves in the future (Ahmed, 2006). To bring these methods on-line, however, Iran will have to invest more in its energy sector. Second, Iran shares some of its oil and natural gas fields with its neighbors (e.g., Qatar). If these jointly-owned

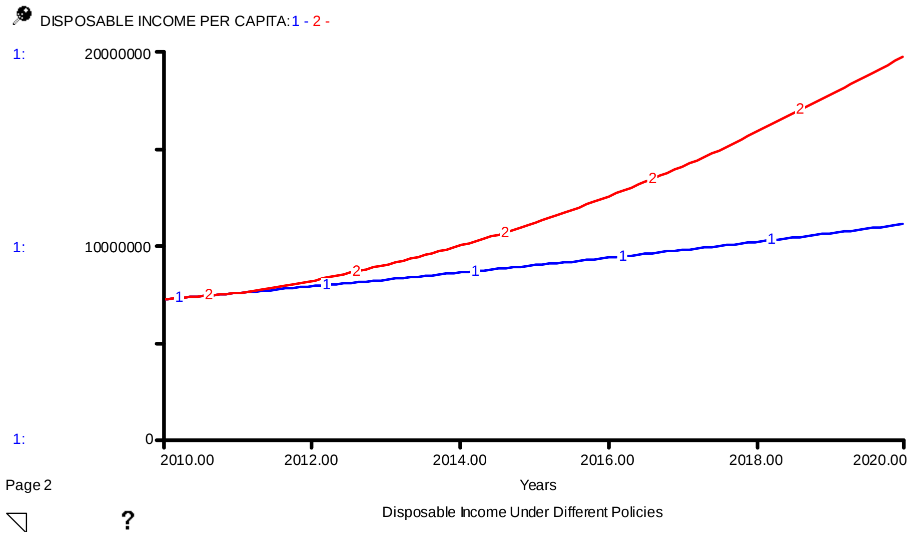

Figure 1.2.23: Time paths for disposable income per capita under the "slow investment down" and "more investment now" strategies (2010-2020)

reserves are not exploited in a timely fashion, they will impose some opportunity costs on the Iranian economy. Investing more in its energy sector now, rather than later, will increase the probability that the jointly-owned reserves can be utilized by Iran. The implications of the "more investment now" versus the "slow investment down" strategies can be tested with the modified M-model by simulating a change in Iranian foreign policy.

To test the "more investment now" strategy, the assumption is made that the Iranian government improves its relationships with the developed countries and, as a result, is able to accelerate its production of oil. More precisely, it is assumed that this about-face in foreign affairs will allow Iran to double its oil production in as little as 1 year[19]. The simulation run embodying this assumption can be compared with an earlier one in which the maximum oil production growth rate was assumed to be 14%. This is the "slow investment down" strategy. The short-term and long-term implications of these strategies can be compared separately. Fig. 1.2.23 shows the time paths for "disposable income per capita" in the short-term (2010–2020). Curve 1 represents the "slow investment down" strategy and curve 2 represents the "more investment now" strategy. Over this narrow period of time it is clear that increasing Iranian oil production capacity at a faster rate can yield higher economic welfare.

Fig. 1.2.24, on the other hand, shows that the story is different in the long run. Although superior in the short-term, the "more investment now" strategy leads to an economic depression in the long-term because the economy cannot

[19]Recall that this was an assumption in the original M-model.

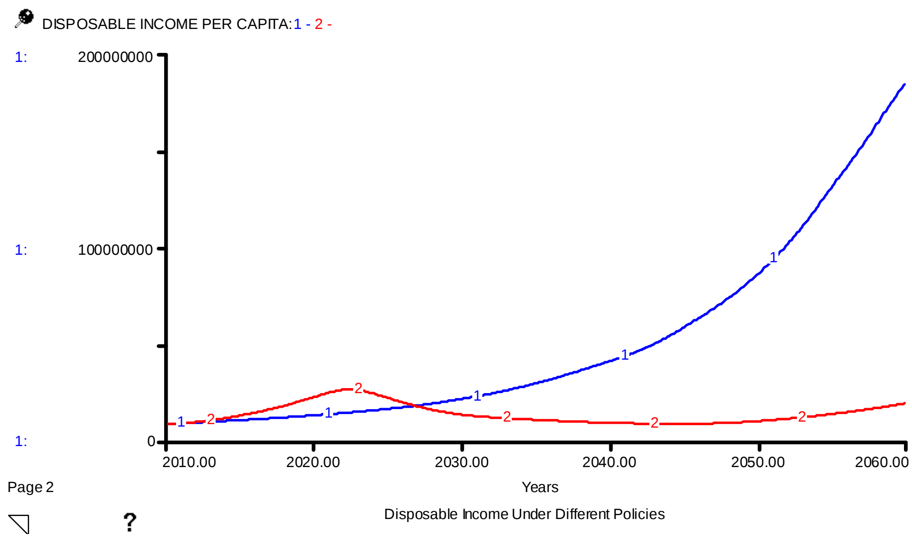

Figure 1.2.24: Time paths for disposable income per capita under the "slow investment down" and "more investment now" strategies (2010-2060)

adjust to a lack of oil revenue caused by depletion.

The robustness of this policy conclusion can now be examined. To conduct this sensitivity test the protocol from section "Behavior Mode Sensitivity" will again be utilized. Further, the same parameters that were varied in the previous section will be changed with the only difference being that, for each sensitivity run, each parameter is given only one new value. Similar to the results presented in Fig. 1.2.22, all of the parameters will be altered simultaneously. Figures 1.2.25 and 1.2.26 show representative results from the policy sensitivity test in both the short and long runs, respectively. In both cases, curves 2 and 4 repeat the same results shown in Figures 1.2.23 and 1.2.24 while, curves 1 and 3 show the time paths generated by the modified M-model with new, randomly chosen, parameter sets. In both, the short and long runs, the behavior modes are insensitive to the parameter changes. The overall conclusion of the test is that the modified M-model's policy recommendations are robust—that is, insensitive to changes in model parameters.

1.3 Conclusion

In this chapter, a classic system dynamics model developed by Ali Mashayekhi in 1978 was resurrected, updated and revalidated. The goal of the model is to investigate the issue of Iranian oil dependency. The original model had predicted that Iran would face a harsh economic recession during the 1980s due to a steep fall in oil revenue caused by natural resource depletion. Thirty-five years later,

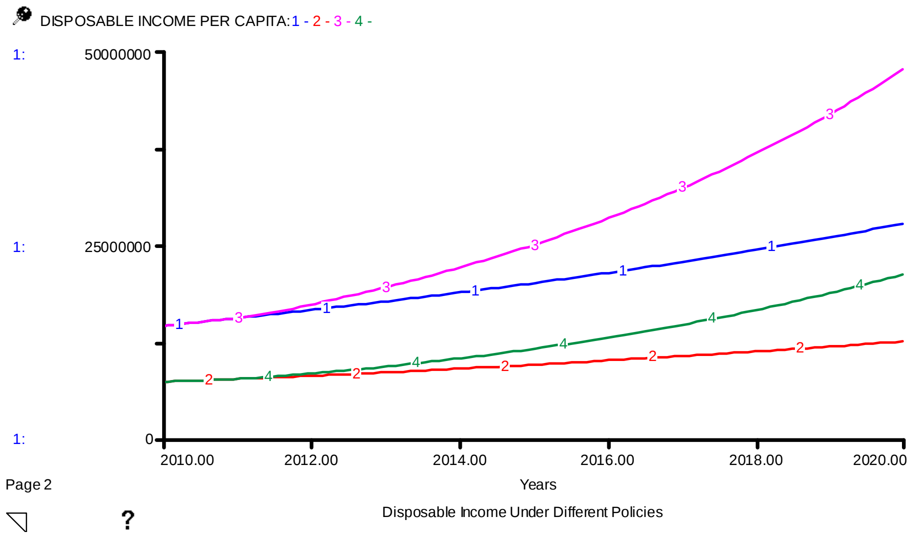

Figure 1.2.25: Sensitivity of time paths for disposable income per capita under the "slow investment down" and "more investment now" strategies (2010-2020)

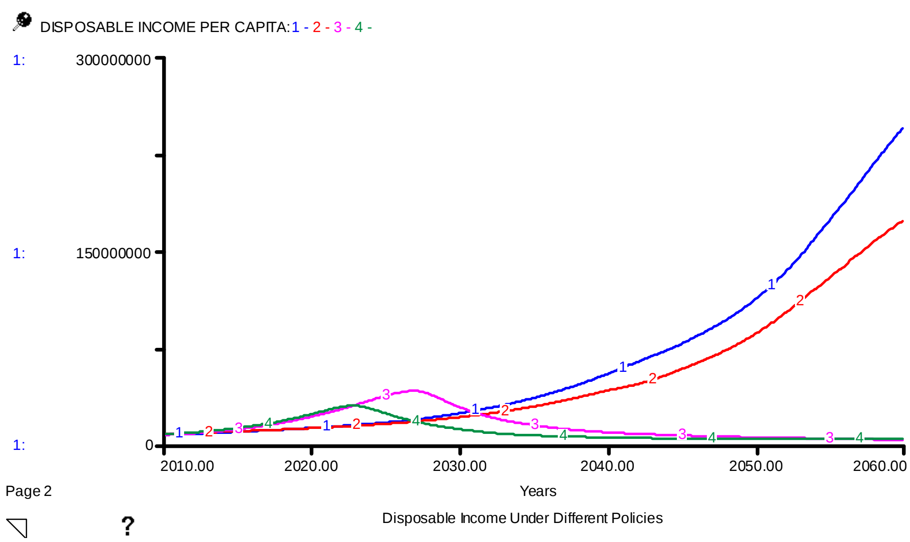

Figure 1.2.26: Sensitivity of time paths for disposable income per capita under the "slow investment down" and "more investment now" strategies (2010-2060)

however, Iran's oil reserves remain intact and the country has not encountered the sort of severe depression that was predicted.

An examination of the original M-model showed that it did not contain the structure necessary to capture the dynamics of the Islamic revolution or the war with Iraq that occurred during the 1980s. Updating the M-model's exogenous variables, modifying some of its assumptions, and recalibrating some of its parameters significantly improved its ability to reproduce Iranian economic history. Revalidation of the M-model has shown that it is fairly robust and generally reliable. Although it is an excellent tool for analyzing questions directly related to the issue of Iranian oil dependency, however, due to its relatively narrow boundary it is an inadequate platform for analyzing many contemporary Iranian macroeconomic policies. Broadening the boundary of the M-model by adding sectors such as a financial market, a foreign exchange market, a labor market, and an energy market would greatly enhance its versatility. As such, it can be argued that the M-model can serve as a foundational platform for future Iranian macroeconomic modeling efforts.

Finally, this chapter can serve as a starting point and archetype for those who wish to develop a system dynamics macroeconomic model of a resource-dependent developing nation. Future research involving the use of the M-model for this purpose should, therefore, address the following issues:

- As previously mentioned, the boundary of the M-model should be broadened to include a financial market, foreign exchange market, labor market, and an energy market.
- The energy sector of the M-model should be revised to address energy–economy interactions. For example, the original M-model and its current modified version contain only one source of energy—oil. The boundary of the energy sector needs to be broadened to include alternative sources of energy and the economics of their substitutability.
- The importation of energy is impossible in both the original M-model and its current modified version. This is not acceptable, particularly when the purpose of the model is to analyze energy–economy interactions.
- The production functions in both the original M-model and its current modified version are very sensitive to their elasticity parameters.
- The formulation of these functions should be modified to eliminate this fragility.
- The modified M-model should be recalibrated to see if it can reproduce the behavior of other "capital-deficient" oil exporting nations such as Nigeria, Algeria, Indonesia, Venezuela, Ecuador, or Mexico that have large populations and significant agricultural sectors.

Chapter 2

A Simulation Model of Katouzian's Theory of Arbitrary State and Society[1]

2.1 Introduction

Over the last century, Iran's economic growth has been fairly unstable, primarily due to the dynamics of its political atmosphere (Bharier, 1971; Issawi, 1971; Floor, 1998). The unsteadiness of Iranian economic growth can be seen in the time series data presented in Fig. 2.1.1. In this figure, Iranian GNP data are divided into two periods—1900 to 1960 and 1960 to 2010—so that the instabilities in the Iranian economy can be clearly identified[2].

An inspection of the figure reveals that the same qualitative pattern of behavior exists in both time periods—i.e., GNP initially grows exponentially until a political disruption takes place. During the period 1900 to 1960, Reza Shah was forced to abdicate during the Anglo-Soviet invasion of Iran in 1941, which was followed by a coup d'état against the democratic governance of Mohammad Mossadegh in 1953. In the period 1960 to 2010, the political system endured a crisis in the mid-1970s that precipitated the 1979 revolution. In both cases, the

[1] This chapter is published in "Langarudi, Saeed P., and Michael J. Radzicki. 2015. A Simulation Model of Katouzian's Theory of Arbitrary State and Society. Forum for Social Economics, June, 1–38. doi:10.1080/07360932.2015.1051076."

[2] Fig. 2.1.1 was created from a combination of two datasets. The first source of data, shown in the left-side diagram, comes from the work of (Bharier, 1971, p. 59), who provides a realistic estimate of Iran's real GNP from 1900 to 1960 in constant 1959 prices. The second source, shown in the right-side diagram, comes from the online portal of Iran's Central Bank (CBI, 2014), which provides data on Iran's real GNP from 1959 to 2010 in constant 1997 prices.

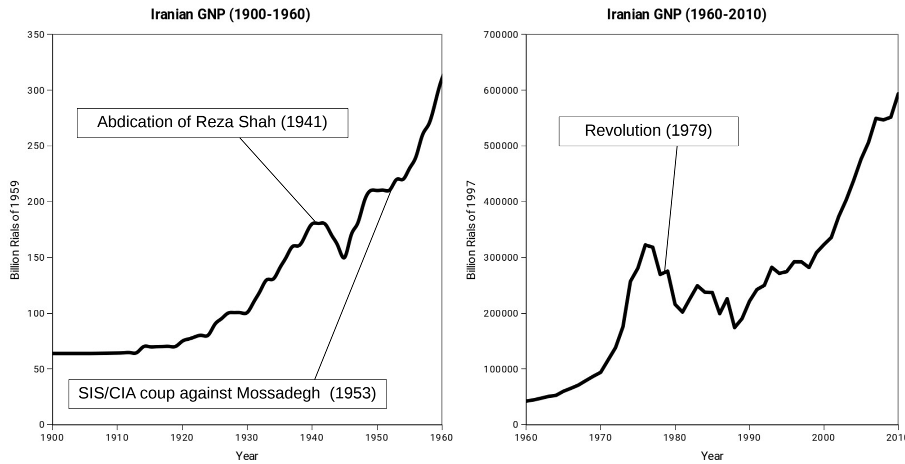

Figure 2.1.1: Real Iranian GNP—in billion Rials at constant prices

Iranian economy collapsed after a period of political instability and it took a while for it to return to its previous pattern of growth. In terms of a more generic and simplified pattern of behavior, the dynamics inherent in Fig. 2.1.1 can be portrayed by the growth–stagnation–growth time shape presented in Fig. 2.1.2. Arguably, a useful theory of Iranian socioeconomic development should be able to replicate this qualitative mode of behavior[3]. In system dynamics modeling, the "target" dynamic behavior mode that is to be replicated or mimicked is known as a "reference mode."

Since the 1970s, there have been many attempts to explain the distinctive dynamics of Iran's macroeconomy[4]. The literature on Iranian economic development is vast and can be broadly divided into two major groups: quantitative analyses and qualitative (descriptive) studies. Quantitative analyses[5], mostly econometric models, are highly dependent on numerical data and thus intrinsically unable to explain Iran's long-term economic dynamics because most Iranian time series data only goes back to 1959. The reliability of these data is also suspect (Amuzegar, 1997). Moreover, the effect of political factors such as revolution and war is normally represented as exogenous inputs into these econometric models, which implies that these phenomena are created by external forces. In fact, the very nature of the methods employed in these studies

[3]Saeed (1992) argues that complex dynamic behavior modes should be "sliced" into simpler qualitative time shapes (i.e., reference modes) so that a system dynamics modeling effort can be directed toward capturing the feedback processes that generate them.

[4]See Esfahani et al. (2013) for a comprehensive review of Iranian macroeconomic modeling efforts.

[5]See for example Habib-Agahi (1971); Beharie (1973); Heiat (1987); Valadkhani (1997); Becker (1999).

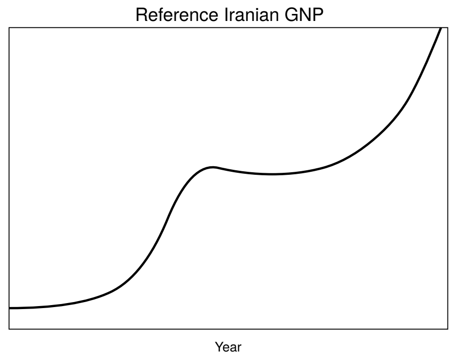

Figure 2.1.2: Reference mode for the qualitative behavior of Iranian GNP

prevents a modeler from integrating Iran's socio-political system into a model of its economic system. As a consequence, most of the modeling studies undertaken by mainstream Iranian economists have been unable to incorporate those features of Iran's socioeconomic system that are key to understanding its dynamics. Stated differently, most quantitative analyses have utilized factors that are merely the result of the complex interrelationships that comprise the Iranian socioeconomic system, rather than the root causes that define the system's complex interrelationships and that generate its dynamics.

Qualitative studies of the Iranian economy, on the other hand, go far deeper into the very complicated and interrelated feedback structures that define the Iranian socio-political system. Some of these studies are more general and try to explain the causes of relative economic underdevelopment in eastern societies[6], while others are case studies that specifically focus on Iran's socioeconomic system[7] and explain "why Iran lagged behind while the west moved forward."[8] Although these studies provide more detailed—and thus, more realistic—explanations for the system's behavior, they lack two important features that are crucial for rigorous scientific work. First, they cannot generate synthetic data that can be formally compared to numerical data from the actual system. Second, rigorous policy analysis is not possible because they cannot be used to run controlled experiments. The purpose of this chapter is to provide a rigorous explanation for Iran's pattern of unstable economic growth. The system dynamics model put forth in this chapter is based on the work of Katouzian (1978, 1981, 1997, 2003, 2004, 2009, 2010, 2011), an economist and historian who created a well-known socio-political-economic theory of Iranian economic

[6]Some of the most well-known theories in this area are "the Asiatic mode of production" of Karl Marx (Shiozawa, 1966), Max Weber's "theory of social and economic organization" (Weber, 1947), and Wittfogel's "oriental despotism" (Wittfogel, 1957).

[7]See for example, Alamdari (2010); Arianpour (2003); Ashraf (1980); Katouzian (1978, 1981, 1997, 2003); Peyman (2003); Piran (2005); Tabatabaei (2001).

[8]This question is the title of a popular book in Iran written by Alamdari (2010).

development. The approach taken in this chapter is to retain the richness of a qualitative study of the Iranian socio-political-economic system and combine it with the rigor of a quantitative analysis.

System dynamics has already been used to test complex, nonlinear, and feedback-rich descriptive economic theories[9]. In the case of Iran, the first and arguably most important application of system dynamics to economics was put forth by Mashayekhi (1978). As described in Chapter 1 Mashayekhi developed a system dynamics model to analyze Iran's long-term economic development options made possible by its oil revenue. Since the focus of this model was oil revenue and its use in economic development, and not the more general issues associated with Iranian political economy, it cannot be used to explain Iran's long-run socioeconomic dynamics[10]. That said, beyond Mashayekhi's work, there has been no serious system dynamics modeling effort aimed at analyzing the dynamics of the Iranian socio-political-economic system.

This chapter represents an initial effort to model the dynamics inherent in Iran's socio-political-economic system. More specifically, Homa Katouzian's theory of arbitrary state and society[11]—a very well-established descriptive theory of Iran's unstable economic development—is translated into a system dynamics model[12], tested for internal consistency, and used for policy analysis[13]. Initially, the model's ability to mimic the irregular dynamics of the Iranian economy is presented. Then, the model is used to test different scenarios and policy prescriptions aimed at improving the behavior of the Iranian socioeconomic system. In this regard, Section 2.2 describes Katouzian's theory of arbitrary state and society. Section 2.3 presents the base run of the system dynamics model of Katouzian's theory and shows how it can mimic the fundamental behavior of Iran's macroeconomy. Section 2.4 reports the results of model validation tests. Section 2.5 explores the implications of altering a couple of key assumptions in the model to determine if its ability to mimic Katouzian's theory is robust or fragile. Section 2.6 outlines some policy experiments tested with the model, while Section 2.7 presents the chapter's conclusions.

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[9] Radzicki (2009) reports some of these efforts in his chapter.

[10] For a detailed and updated review of Mashayekhi's model which explores its capabilities and limitations, see Chapter 1 or Langarudi and Radzicki (2013)

[11] The causal relationships that underlie Katouzian's theory will not be justified here as this evidence exists in Katouzian's numerous works (Katouzian, 1978, 1981, 1997, 2003, 2004, 2009, 2010, 2011). The interested reader can easily refer to them for additional information.

[12] A system dynamics model is essentially an institutionalist pattern model. See Radzicki (1988, 1990a,b) for a comprehensive discussion of economic methodology and its relationship to system dynamics modeling.

[13] For a lively discussion on the challenges inherent in translating someone else's descriptive theory into a system dynamics model, see Wittenberg (1992); Sterman (1992); Radzicki (1992); Barlas (1992); Wittenberg and Sterman (1992).

2.2 Katouzian's Theory of State and Society

This section describes Katouzian's theory[14] in a very concise form using the conceptual tools of system dynamics[15]. The structure of the Katouzian model is shown in Fig. 2.2.1. An explanation of this structure begins with the model's simple engine of economic growth in which a portion of Iran's *disposable income*, determined by the marginal propensity to save (MPS), is saved. This flow of saving is accumulated in the model's stock of *Society Savings* and is available for investment. A flow of *society investment* spending builds up the model's stock of *Society Capital*[16], which in turn is used to generate *output*. Higher levels of *output* provide the Iranian citizenry with a higher flow of *disposable income*, some of which is again invested in *Capital*. This defines a self-reinforcing feedback loop that drives economic growth[17]. A balancing feedback loop that creates fiscal drag through taxes also exists. Higher *output* generates higher tax payments which, in turn, lowers *disposable income* and limits saving, investment, and economic growth.

Katouzian argues that the primary mechanism preventing Iran from experiencing the same sort of economic development enjoyed by Western countries is the low rate of saving and investment that is mostly due to the constant insecurity surrounding property rights, as well as the overall unpredictability of the Iranian socioeconomic system caused by the systematic state confiscation of property. Throughout history, Iran has endured a very low level of security for those who own private property. The state could confiscate the property of its citizens at any time, without any legal justification. In fact, the will of the ruler was sufficient to make any procedure legal. This insecurity with respect to property rights was often exacerbated by lawless behavior that occurred during and after episodes of political unrest. Katouzian asserts that people will save and invest less if they feel economically insecure. So, in the Katouzian model, while the flow of *confiscation* transfers some of the private sector's *Capital* to the state, it also discourages saving.

The flow of *confiscation* in the Katouzian model depends upon two factors: *Political Power* and the government's level of *Corruption*. The more *Political Power* the government has and the more corrupt it is, the more likely it will be that *Confiscation* will take place[18]. *Corruption*, in turn, depends on the amount of respect for the law[19] shown by the nation's citizenry. *Respect for*

[14] The structure described here represents a synthesis of the ideas presented in numerous publications written by Katouzian. See Footnote 11.

[15] Readers who are unfamiliar with the conceptual tools of system dynamics modeling are encouraged to consult a basic primer on the subject such as: `http://www.systemdynamics.org/DL-IntroSysDyn/index.html`.

[16] In the model, "capital" includes all types of income-generating assets including land, commercial and industrial capital, plant and equipment, etc.

[17] Of course, this type of basic economic growth mechanism is found in many models in modern economic growth theory.

[18] The literature on the causes and consequences of corruption or kleptocracy in developing nations is vast and a comprehensive survey is beyond the scope of this chapter. The interest reader should consult Søreide (2014) for an excellent overview.

[19] Here, the law means a written and constitution-based law, which remains constant over

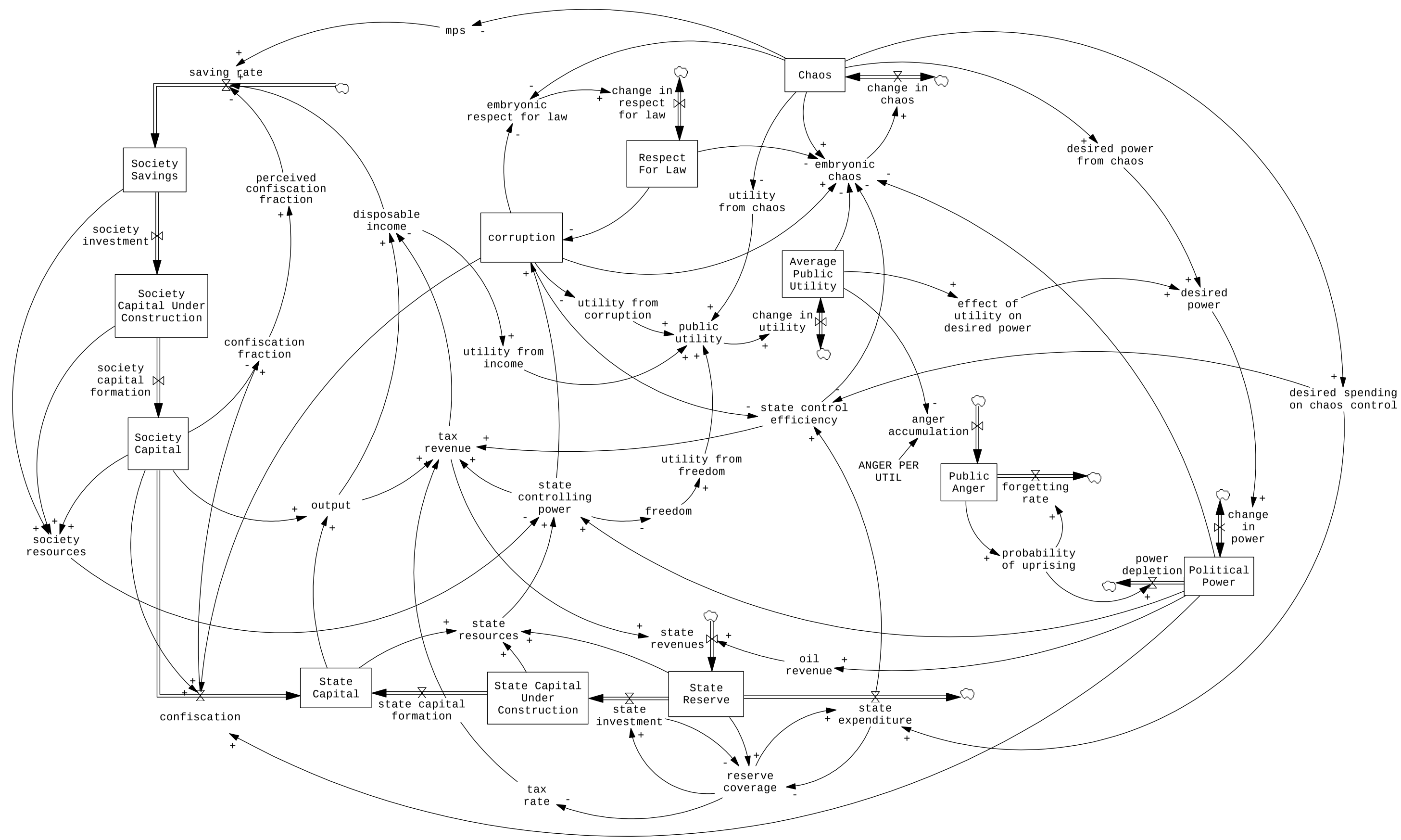

Figure 2.2.1: Overview of the model structure

Law (or, in short, lawfulness) is an indicator of the "arbitrariness" of a society. In other words, lawlessness is a key characteristic of an arbitrary culture. Higher levels of an arbitrary culture mean less respect for the law, and vice versa. An arbitrary culture grows faster in a society that is suffering from lawlessness. An arbitrary ruler prefers an arbitrary environment since respect for the law is a threat to his power. In other words, an arbitrary ruler instinctively knows that he should restrain the power of the law, otherwise the law will limit his power. This mechanism—i.e., more arbitrary power leading to less respect for the law, which in turn facilitates the additional accumulation of power, and thus more arbitrary power—creates a self-reinforcing feedback loop that is one of the fundamental substructures of Katouzian's theory. In Fig. 2.2.1, this positive feedback loop works its way through *Political Power*, *state controlling power*, *Corruption*, *Respect for Law*, *Chaos*, *desired power*, and back to *Political Power*.

Respect for Law can be damaged by social *Chaos*. In a chaotic socioeconomic system, the law may easily be ignored or broken by individuals. But, *Chaos* will also be affected by lawfulness. Since lower *Respect for Law* will increase chaotic acts, this chain of cause and effect creates a self-reinforcing feedback loop that can produce a vicious cycle. Similar mutual relationships exist between *Respect for Law* and *Corruption*. That said, the main driving force behind *Corruption* is the amount of respect for the law possessed by the citizenry. A society with little respect for the law is a breeding ground for *Corruption*. If the level of lawfulness is high (low), the level of *Corruption* will be low (high) because people will be less (more) inclined to engage in unlawful actions such as bribery and fraud. If significant levels of *Corruption* persist in a society, people start to feel that they are losing socioeconomic benefits by adhering to the rule of law. As such, they gradually follow the same path as lawless people so as to gain some of the advantages of *Corruption* and lawlessness. This negative linkage from *Corruption* to *Respect for Law* creates another positive feedback loop that can generate a destructive—or constructive, depending on which way the loop is working—impact on the Iranian socioeconomic system.

In the Katouzian model, *Corruption* is driven by *state controlling power*, which is a measure of the state's political-economic power. The economic power of the state is measured by the ratio of the state's economic resources to the total economic resources of the country. When the state controls a greater share of economic and political power, it is inclined to restrict more and more personal freedom, particularly freedom of speech, which leads to a weaker system of checks and balances over the state's performance. Weaker checks and balances, in turn, lead to a higher level of *Corruption* in Iranian society.

As was previously mentioned, in Katouzian's theory, Iran's *marginal propensity to save* and *Respect for law* are influenced by the level of social *Chaos*. This begs the question as to what generates *Chaos*. *Chaos* in Katouzian's theory emerges whenever the central government is weak—that is, when Iran's *state control efficiency* is low. *State control efficiency* is determined by the amount of financial resources the state possesses versus the amount of financial resources

time and place.

that are required to control the current level of *Chaos*. *Chaos* is also influenced by *Respect for Law* and *public utility*. The latter is an indicator of short-term public satisfaction and negatively impacts *Chaos* since unsatisfied citizens may participate in violent activities or breach social norms.

Public utility plays a key role in the accumulation of power by the arbitrary ruler. Higher *public utility* allows the arbitrary ruler to accumulate more power, while lower *public utility* will limit the growth rate of *Political Power* or even reduce it when it goes negative (i.e., negative *public utility* generates *Public Anger*).

In the Katouzian model, there are several inputs to the *public utility* function including *disposable income*, *Chaos*, *Corruption*, and *freedom*, the latter of which is inversely associated with *state controlling power*. While *disposable income* and *freedom* have a positive impact on *public utility*, *Chaos* and *Corruption* have a negative impact.

Higher levels of *Chaos*, ceteris paribus, generate a need for more resources so that the state can still control the socioeconomic system. This increases the flow of *state expenditure* and drains *State Reserve*. A decline in *State Reserve*, in turn, causes the *tax rate* to increase. Of note is that *tax rate* goes up if *Chaos* increases, but this pressure does not necessarily translate into a higher flow of *tax revenue*. This is because the amount of revenue the state can actually collect is also determined by the economy's annual *output*, as well as the amount of *state controlling power* and state control efficiency. In other words, better control by the government and/or a higher level of national economic output can generate higher *tax revenue*.

The flows of *tax revenue* and, since 1903, *oil revenue* add to the stock of *State Reserve*. In the Katouzian model, the *State Reserve* is used for *state investment* and for controlling *Chaos* (via spending on measures that enhance *state control efficiency*). In addition to the flow of *confiscation*, *state investment* builds up the *State Capital*, which contributes to the production of Iran's total economic *output*. *State Capital*, along with *State Reserve* is part of Iran's *state resources*, which are an important determinant of Iran's *state controlling power*.

It is important to note that in the Katouzian model, the flow of *oil revenue* is directly linked to *Political Power*. In fact, it is assumed that a relatively powerful central authority is necessary to effectively export oil. Historical data justify this assumption. Fig. 2.2.2 shows how major political incidents have influenced the stream of Iranian oil revenue over time. Slightly before, during, or after each incident, there has been a steep decline in the export of oil. Experimentation with the Katouzian model, however, shows that its dynamic behavior and policy implications are insensitive to this assumption[20].

Continuing with the explanation of the model structure presented in Fig. 2.2.1, higher taxes reduce *disposable income* and hence decrease *public utility*. As mentioned earlier, *public utility* determines the amount of *Political Power* an arbitrary ruler can accumulate. The other factor that helps the arbitrary ruler gain *Political Power* is the level of *Chaos* in Iranian society. As *Chaos* grows,

[20]See Section 2.5.2 for details of this simulation experiment.

the public demands a more powerful ruler who can bring stability and security to society. The arbitrary ruler uses this opportunity to seize more power. As his *Political Power* grows, his *state controlling power* increases, which helps him to better control *Chaos*. A decline in *Chaos* increases the popularity of the arbitrary ruler even further, which leads to an even greater accumulation of *Political Power*. This positive feedback loop helps arbitrary power grow rapidly, but it also limits the amount of *freedom* in Iranian society. A decrease in *freedom* weakens *public utility* and also weakens the Iranian system of checks and balances. As a result, *Corruption* starts to increase.

Higher levels of *Corruption* cause *public utility* to decline further and the flow of *confiscation*, which reduces *disposable income* and thus *public utility*, to increase. It also reduces *state control efficiency* which, in turn, causes *Chaos* to increase. Since the state now needs more financial resources to boost its control measures, it increases *tax rate*, which reduces *public utility* even further. As this vicious cycle unfolds, people save less due to their insecurity with respect to Iran's socioeconomic atmosphere. Eventually, the government loses its power since it cannot provide Iranian society with socioeconomic security.

The completion of the Katouzian cycle occurs when the government loses its power, *Chaos* grows to a very high level, and the public begins to demand a new, powerful, ruler to bring peace and stability to society. Katouzian calls this vicious and repetitive cycle "arbitrary rule-chaos-arbitrary rule." This reference pattern of behavior is shown in Fig. 2.2.3. The *Political Power* of the arbitrary ruler (dotted line) and the level of societal *Chaos* (solid line) are shown in this figure. In order to satisfactorily represent Katouzian's theory, the oscillatory behavior of these variables, with the correct phase lag, must be replicated by the simulation model.

2.3 Base Run of the Katouzian Model

In this section of the chapter, the base run behavior of the Katouzian model is explored to determine whether or not its dynamics are consistent with the historical behavior of the Iranian socio-political-economic system. In particular, the model's behavior is compared against the "arbitrary rule-chaos-arbitrary rule" cycle described in Fig. 2.2.3 and the qualitative behavior of Iranian time series data presented in Fig. 2.1.2. Since Katouzian's theory takes a historical perspective going back as far as the nineteenth century, the Katouzian model is simulated for a 200-year time period.

To generate the base run simulation, the Katouzian model is initialized with mid-range levels of *Political Power*, *Chaos*, and *Corruption*, relatively low levels of *Public Anger* and *public utility*, and a very low level of *Respect for Law*. These initial values, along with the maximum possible variation of each variable, are reported in Tab. 2.3.1. *Political Power*, *Corruption*, and *Respect for Law* are scaled variables with a possible range of variation between 0 and 1. For example, when *Political Power* is 0.2, it means that 20% of the political power of Iranian society is under the control of an arbitrary ruler, and when *Respect*

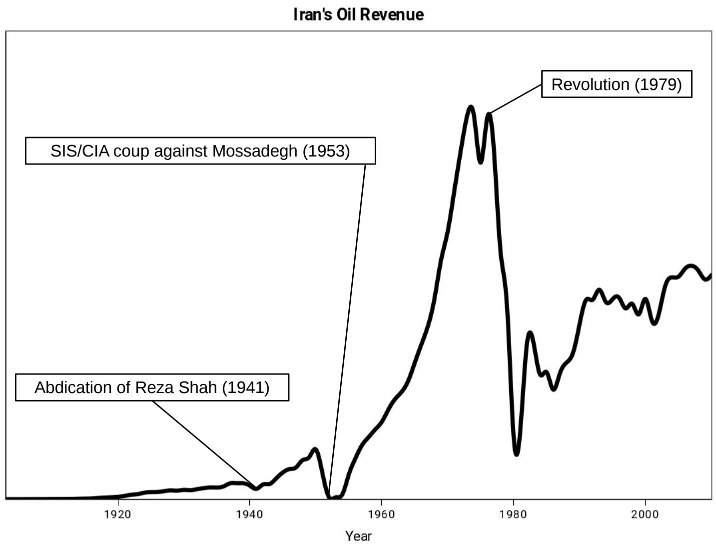

Figure 2.2.2: Historical behavior of Iran's oil revenue marked by major political incidents (CBI, 2014)

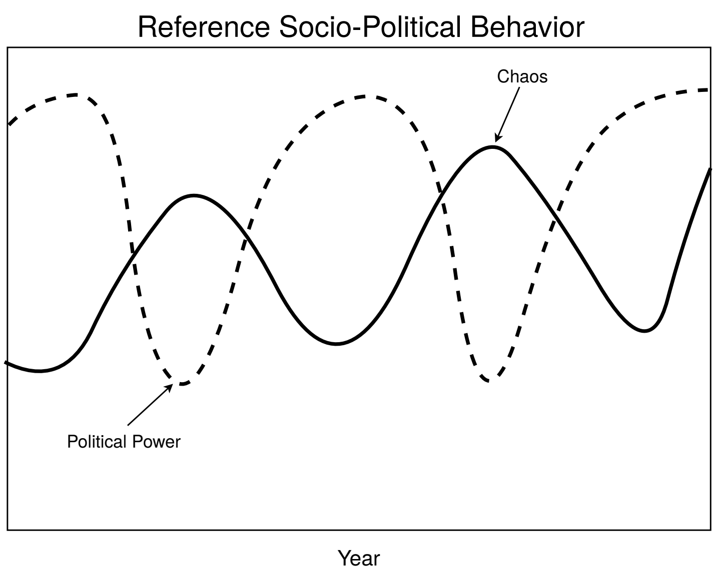

Figure 2.2.3: Reference modes of behavior of Iranian socio-political system

Table 2.3.1: Initial values and potential variation range of key variables for base run simulation

Variable	Minimum	Base value	Maximum	Unit
Political Power	0.00	0.50	1.00	Dimensionless
Chaos	0.00	0.50	$+\infty$	Dimensionless
Public Anger	$-\infty$	0.10	$+\infty$	Util/Year
Corruption	0.00	0.50	1.00	Dimensionless
Respect for Law	0.00	0.05	1.00	Dimensionless

for Law is 0.9, it can be interpreted as meaning that 90% of Iranian society follows the rule of law. *Chaos* can theoretically vary from 0 to infinity, where 0 indicates no chaotic action in Iranian society at all and larger numbers indicate greater levels of chaos in Iranian society. Despite a theoretical maximum value of infinity, experimentation with the Katouzian model indicates that *Chaos* rarely goes beyond a value of 3. *Public Anger* is a stock that accumulates public dissatisfaction over time. *Anger* is measured in *Utils*[21] and the stock of *Public Anger* can theoretically fill without limit, although a dissipation flow called *forgetting rate* helps to prevent this from occurring. When this variable is zero, it means that Iranian society is indifferent toward the government's status and actions. However, as the stock of *Public Anger* fills the probability of an uprising occurring increases. *Public utility* reflects the short-term satisfaction of Iranian society originating from four major factors: the economy, chaos, corruption, and freedom. It is measured by *Utils/Year* and it can vary from -1 to +1. When the stock of *Average Public Utility* turns negative, it activates the flow of anger accumulation while a positive value of *Average Public Utility* causes anger accumulation to deplete.

Fig. 2.3.1 shows simulated Iranian total economic output from the Base run of the Katouzian model. An inspection of the figure reveals that the model's behavior mimics the qualitative long-run time shape defined by the reference mode of Fig. 2.1.2 reasonably well. In other words, during each cycle, *Total Economic Output* grows exponentially, reaches a peak, and then stagnates for a period of time before resuming its path of exponential growth.

Although it is clear that the Katouzian model can mimic the long-run qualitative behavior of Iranian macroeconomic data, it is also important that it captures the qualitative dynamics of the socio-political system described by Katouzian. Fig. 2.3.2 presents the base run dynamics of Political Power and Chaos generated by the model. An examination of the figure reveals that the model can indeed "tell the story" of Iranian economic development in a manner consistent with Katouzian's theory.

[21]In the Katouzian model, as in neoclassical microeconomics, *Utils* represent units of satisfaction/dissatisfaction. Of course, because utility is not a characteristic that is directly

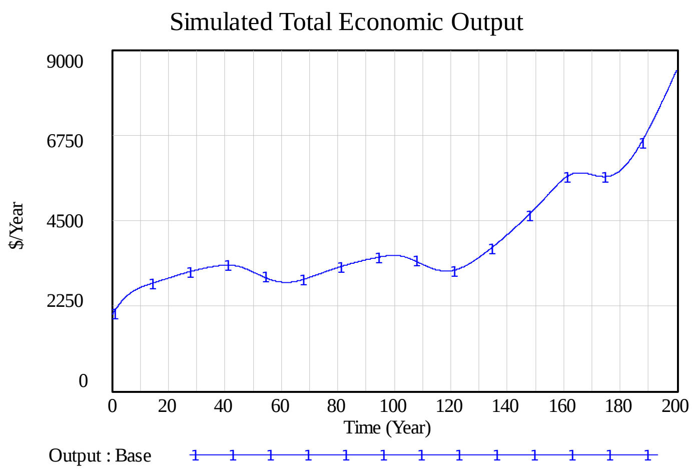

Figure 2.3.1: Base run simulation of the Katouzian's model (Total Economic Output)

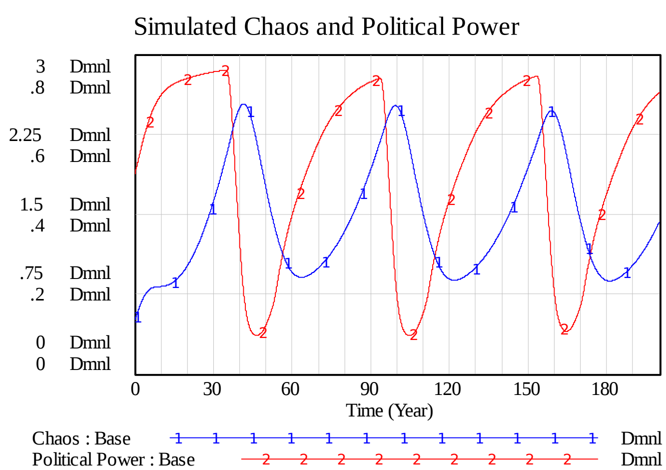

Figure 2.3.2: Base run simulation of the Katouzian's model (Chaos and Political Power)

To have a better understanding of the results, only one cycle of "arbitrary rule-chaos-arbitrary rule" (the period 50 to 100[22]) is presented in Figures 2.3.3 and 2.3.4. Fig. 2.3.3 includes *disposable income*, *Chaos*, *Corruption*, and *freedom*, while Fig. 2.3.4 presents *Political Power*, *Public Anger*, and *public utility*. *Public Anger* is initially declining during this period because *public utility* is still positive. *Public utility* is positive because *Corruption* and *Chaos* are declining and because the level of *freedom* is still high. This atmosphere allows arbitrary power to start growing. As Iranian state power grows, it can better control chaos, so *Chaos* starts to decline further. The success of the state in controlling chaos helps it to attract more public support. With this support in hand, the state gains additional power, which enables it to further suppress *Chaos* (and thus make the citizenry even happier), which in turn results in an even greater level of *Political Power*. As arbitrary power increases, *Corruption* increases and *freedom* declines. This has a destructive impact on *public utility*. Increased *Corruption*, which harms the efficiency of the state's *controlling power* while reducing *public utility*, generates higher levels of *Chaos* (which was declining until time period 70). Lower *public utility*, lower *control efficiency*, and higher levels of *Chaos* not only make it difficult for the state to collect taxes but also increase its spending. As a result, the state's financial resources decline and its controlling power becomes even weaker. In other words, even though the state is very powerful at this time, its efficiency is low because it cannot effectively control the socioeconomic chaos. This creates a significant sense of dissatisfaction in Iranian society. The decline in *public utility*, and hence rising *Public Anger*, exacerbates *Chaos*, which brings *public utility* down to even lower levels. This creates a vicious circle, which finally causes the ruler to lose his power.

Of particular interest in this base run is the behavior of *disposable income*. It declines while *Political Power* increases and it starts to grow when arbitrary rule reaches the end of its era. This behavior is primarily due to the long time delays in capital accumulation and depreciation. In summary, simulation of the Katouzian model indicates that it is internally consistent. In other words, its structure is sufficient to endogenously generate behavior that mimics the reference mode that it is supposed to explain (i.e., Figures 2.1.2 and 2.2.3).

2.4 Model Validation

Over the years, system dynamicists have assembled a comprehensive list of tests to which a model can be subjected in order to build confidence among its users[23]. The Katouzian model has been subjected to these tests. Some of the

measurable, *Utils* do not represent an actual unit of measurement such as inches or pounds.

[22]The dynamic behavior over any particular period of time in Figures 2.3.3 and 2.3.4 does not necessarily correspond to actual historical periods or events. Rather, dividing the simulation run into different time periods makes it easier to understand the model's pattern of behavior.

[23]See for example Forrester (1973); Peterson (1975, 1980); Mass and Senge (1978); Forrester and Senge (1980); Sterman (1984); Radzicki (2004); Barlas (1996); Oliva (2003).

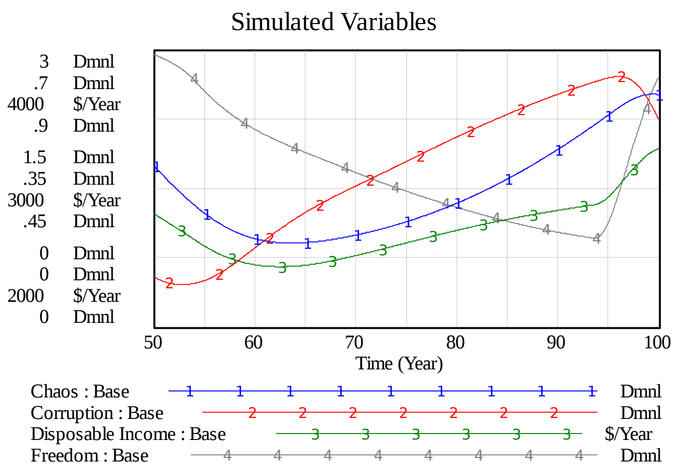

Figure 2.3.3: Base run simulation of the Katouzian's model (Determinants of Public Utility [Period 50–100])

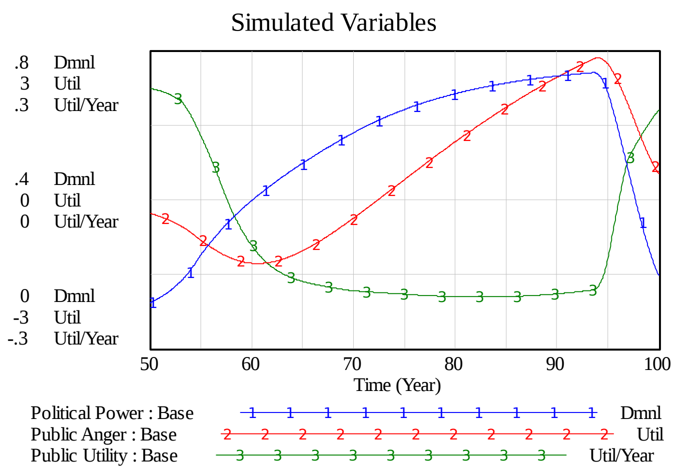

Figure 2.3.4: Base run simulation Katouzian's model (Political Power, Public Anger, and Public Utility [Period 50-100])

test results have already been reported in previous sections of this chapter[24]. Some of the other tests have been conducted automatically with the simulation software as part of the model construction process—e.g., testing the dimensional consistency of each equation and testing the impact on model behavior arising from integration error[25]. This section summarizes the results of other important tests of model validity.

2.4.1 Boundary adequacy

Strictly speaking, system dynamics modelers do not model systems but rather problems from a systems perspective. As a consequence, system dynamicists must choose what aspects from the actual system to include, and what aspects to exclude, from their models. The conceptual fence that separates the variables that are included from those that are not is called the model's boundary. The criterion that is normally used to help a system dynamicist decide on which side of the fence a particular variable should reside is whether or not it can contribute to an endogenous, closed-loop, explanation for the problem to which the model is being addressed.

The boundary of the Katouzian model can be said to be adequate because it generates its behavior endogenously via closed feedback loop structures and its behavior mimics the reference mode. In other words, it does not rely on exogenous variables to "drive" its behavior and "fit the data." In fact, the Katouzian model's only exogenous variable is oil revenue which, ironically, can be considered as both an endogenous and exogenous variable. More specifically, oil revenue is endogenous because it is influenced by *Political Power*. As was previously discussed, the model assumes that a more powerful government has better control over oil exports and, as such, can gain more revenue from this source (see Section 2.2—particularly Fig. 2.2.2—for more details). On the other hand, oil revenue is also exogenous because its growth rate depends on an exogenous ramp function, which creates an artificial growth pattern to replicate the expansion of oil production and exports over time. The good news is that the exogenous portion of the behavior of oil revenue does not detract from the model's validity because, as will be shown below, simulation experiments indicate that Katouzian's "arbitrary rule-chaos-arbitrary rule" cycle is not significantly influenced by it. Moreover, those factors that may impact oil revenue (e.g., the global demand for oil, oil prices, etc.) are outside of the scope of the model and its boundary.

In terms of factors that have been excluded from the Katouzian model that may be significant, two leap to mind. The first, Iran's population, may also be the most important as the inclusion of a demographic sector would enable the

[24]That is, the causal structure of the model has already been described in Section 2.2 and the behavior reproduction tests have been reported in Section 2.3.

[25]The complete documentation of the Katouzian model, along with all variable definitions and complete equation specifications, is available in electronic form from the author. The model was created in Vensim and a free version of this software (`http://vensim.com/download/`) is available so that interested readers can reproduce the simulations presented in this chapter and run simulation experiments of their own choosing.

model to be used for a significant amount of additional policy analysis. The second is factors that influence *public utility* and *Public Anger* such as income inequality would almost certainly alter the model's behavior and increase its explanatory power. Of course, the only way to know for sure how the effects of these factors would ripple their way through the system is to include them within the model's boundary and run simulation experiments.

2.4.2 Sensitivity analysis

One way to determine the robustness of the results from a simulation model is to perform a formal sensitivity analysis. To determine the robustness of the Katouzian model, its important parameters and initial values were subjected to Monte Carlo sensitivity testing. The values chosen for the analysis, and the ranges over which they were tested, are summarized in the Appendix A. Generally speaking, the model's fundamental behavior is insensitive to a wide range of variations in its parameters and initial values. Fig. 2.4.1 presents the results of one of the univariate sensitivity simulation runs for the main variables of the Katouzian model including *disposable income*, *Political Power*, *Respect for Law*, *Corruption*, *Chaos*, and *public utility.* In this sensitivity test, each of the selected parameters and initial values was randomly varied 200 times for a total of 5,800 simulation runs. An inspection of Fig. 2.4.1 shows four levels of confidence in each time series plot: 50%, 68.4%, and 95.4%. Each level of confidence indicates the percentage of the simulation runs that lie within the corresponding area shown on its graph. Of note is that 95.4% of the simulation runs behave qualitatively similar to the base case simulation. The model exhibits an oscillatory behavior mode for majority of simulation runs. Most importantly, the pattern of periodically interrupted economic growth, as well as the oscillations in *Political Power*, appears in all of the simulation runs.

Even multivariate sensitivity simulations show that the model's behavior is very robust. Fig. 2.4.2 illustrates the result of 200 sensitivity simulations in which all the selected parameters and initial values were randomly varied simultaneously over their selected ranges. The results at the 90% level of confidence show that the model's pattern of periodically interrupted economic growth persists irrespective of the values chosen for parameterization and initialization.

Additional sensitivity experiments run on the Katouzian model that are not presented here reinforce the conclusion that its behavior is very robust. Indeed, the only parameters that were found to significantly alter the model's behavior when varied over a large range of values were: *Initial Corruption*, *Initial Respect for Law*, *Society Memory*, and *Time to Change Power*[26].

2.4.3 Other validation tests

The Katouzian model was also tested for extreme conditions, behavior anomalies, and surprise behavior, which are all part of the comprehensive list of tests

[26]The model's behavior was only significantly altered when the parameters and initial values were pushed beyond the ranges that are reported in the Appendix A.

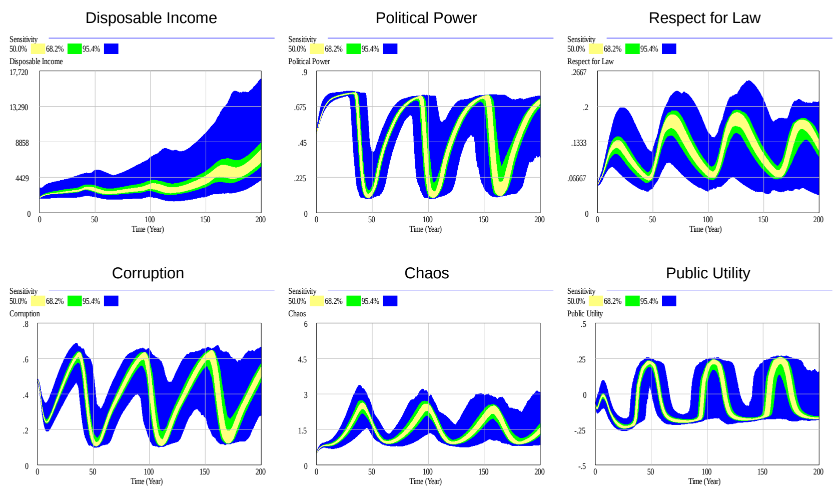

Figure 2.4.1: Sensitivity simulation results of Katouzian's model—levels of confidence for 5800 univariate runs

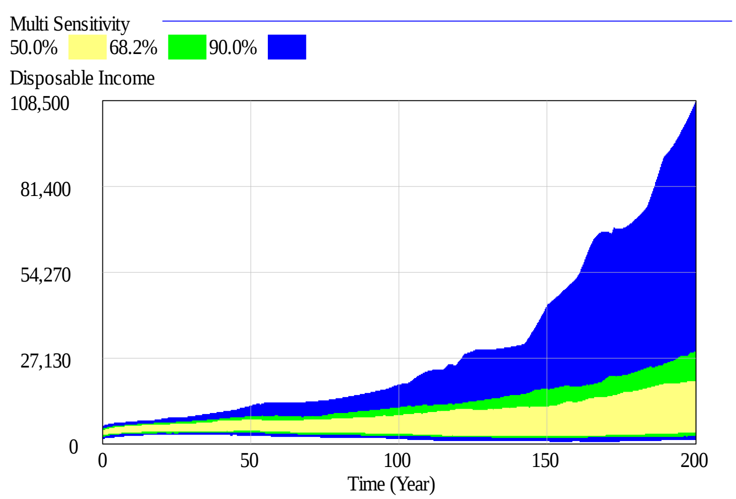

Figure 2.4.2: Sensitivity simulation results of Katouzian's model—levels of confidence for 200 multivariate runs

to which system dynamics models are routinely subjected. Of note is that early versions of the Katouzian model did not pass all of these tests. These failures were extremely valuable in helping to reveal and understand the system's fundamental dynamics and hence in evolving the model toward its current state. Fortunately, the version of the model presented in this chapter could pass all these validation tests successfully.

2.5 Altering Some Key Assumptions

This section presents the results of two simulation experiments run on the Katouzian model which were aimed at determining how sensitive the model's behavior is to changes in some of its fundamental assumptions. The two scenarios that were examined are: (1) increasing the initial level of *Respect for Law* from the base simulation run to determine whether Iran's arbitrary characteristics are indeed the major reason why it has historically lagged behind the Western world's pace of development and (2) eliminating oil revenue from the base simulation run to determine whether the "arbitrary rule-chaos-arbitrary rule" cycle exists without oil revenue as Katouzian claims.

2.5.1 Simulation with higher initial Respect for Law

As mentioned earlier, lawfulness in society is one of the fundamental drivers of economic development in Katouzian's theory. Stated differently, Katouzian theorizes that an arbitrary society, and particularly one ruled by an arbitrary ruler, discourages respect for the law, which in turn impedes economic development. The beauty of having a formal simulation model of Katouzian's theory is that this central hypothesis can be tested. If Katouzian's theory is valid, then an initial model condition in which Iran's arbitrary power characteristics are weak should be able to generate a significantly greater pattern of economic development. To perform this test, the initial value of *Respect for Law* is increased from 0.05 to 0.2 and the model re-simulated. The new simulation run is named *Higher Initial Respect for Law* (HIRL) and its results are shown in Fig. 2.5.1. An inspection of the figure reveals that compared to the base case simulation run: (1) *Political Power* is more stable and political downfalls are less severe. (2) *Respect for Law* shifts upward with less frequent oscillations. (3) The oscillatory behavior of *Corruption* has a smaller amplitude and a longer rate of expansion. (4) *Chaos* declines significantly and is more stable. (5) Fluctuations in *public utility* are smoother with less frequent oscillations and smaller amplitudes. (6) *Disposable income* grows exponentially at a higher rate.

The results of this simulation experiment appear to support Katouzian's hypothesis that Iran's arbitrary characteristics are the major reason why it has historically lagged behind the Western world's pace of development.

2.5.2 Simulation without oil revenue

Another interesting test that can be performed on the Katouzian model involves the well-known theory of the "natural resource curse." According to this theory, natural resource abundance is negatively correlated with economic growth[27]. Sachs and Warner's (1995; 2001) cross-sectional data analysis, which supports this inverse relationship between natural resource abundance and economic growth, is one of the most widely cited source. There is also an emerging literature, including Brunnschweiler (2008) and Brunnschweiler and Bulte (2008), which argues that the natural resource curse does not exist and, in fact, resource abundance positively affects economic growth. Thus, as Stijns (2005) asserts, there is no clear-cut answer in the empirical literature as to whether natural resource abundance is a "blessing" or a "curse." Finally, the resource/growth literature is also saturated with lively debates over the impact of resource abundance on a society's political regime[28].

The Katouzian model can be used to examine the interactions among oil revenue and economic, social, and political development in Iran. Since the base simulation run already includes oil revenue, it can be used as a benchmark against which a "non-oil" simulation run can be compared. In order to have a better understanding of the impact of oil revenue on the model's behavior, it is necessary to know the magnitude of oil revenue that is incorporated into the base settings of the model. Fig. 2.5.2 shows that oil revenue starts to grow at time 100 and continues to grow to about 28% of total State Revenue at time 200.

Fig. 2.5.3 presents a comparison between model simulations in the base run and in a non-oil revenue run. Although oil revenue clearly makes an enormous difference to the economic development of Iran (i.e., Iran's *disposable income* is much higher in the base case), the overall behavior of the Katouzian model stays the same (i.e., *Political Power*, *Respect for Law*, *Corruption*, *Chaos*, and *public utility* all behave essentially the same way in each simulation run). The salient point is that this simulation result corroborates Katouzian's claim that oil revenue does not change the overall behavior of Iran's socio-political system. In other words, the same "arbitrary rule-chaos-arbitrary rule" cycle exists with or without oil revenue.

In order to test the possibility that the simulation results presented in Fig. 2.5.3 are only due to an amount of oil revenue, that is too small to make a difference, the *Non-Oil* test was repeated with the base of the *Ramp* function increased by a factor of 10. The results of this experiment are shown in Fig. 2.5.4.

Likewise the previous simulation experiment, increased oil revenue has no significant influence on the long-term oscillatory behavior of the socio-political system. It does, however, increase *Corruption* and *Chaos*. It also reinforces *Political Power*, though not decisively. This result is consistent with Katouzian's

[27]For recent surveys on this issue, see van der Ploeg (2011); Frankel (2012).

[28]See for example, Aslaksen (2010); Basedau and Lacher (2006); Brunnschweiler (2008); Cesari (2011); Karl (1997); Ross (1999, 2001, 2008); Tsui (2011).

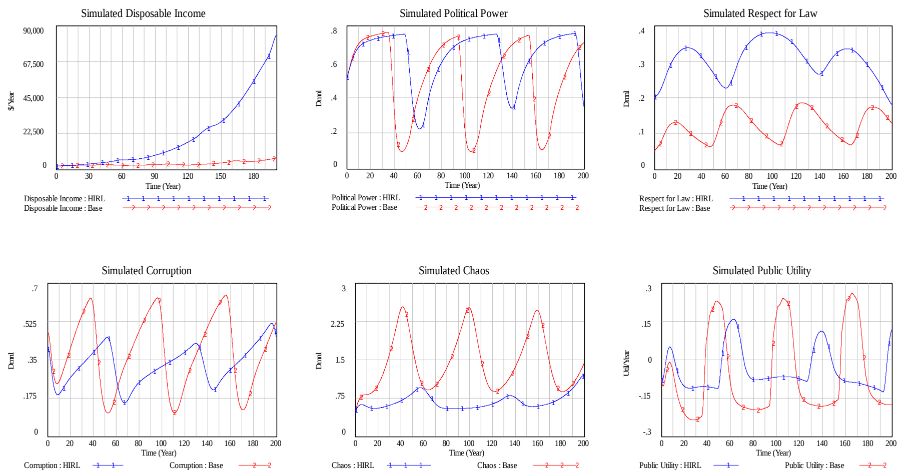

Figure 2.5.1: Ssimulation results of Katouzian's model (base vs. HIRL)

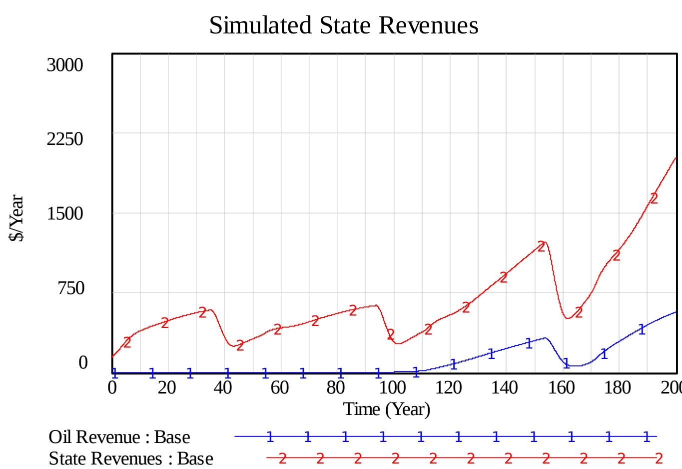

Figure 2.5.2: Oil revenue vs. state revenue (base simulation of Katouzian's model)

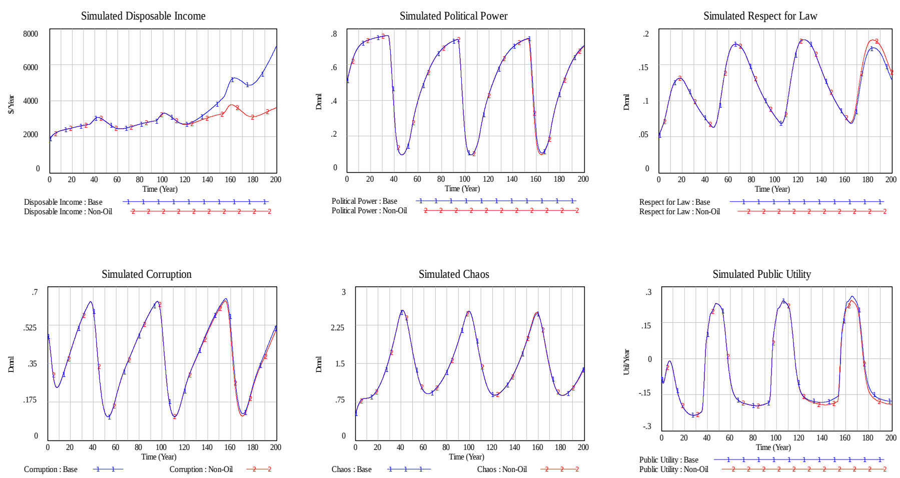

Figure 2.5.3: Simulation results of Katouzian's model (base vs. non-oil)

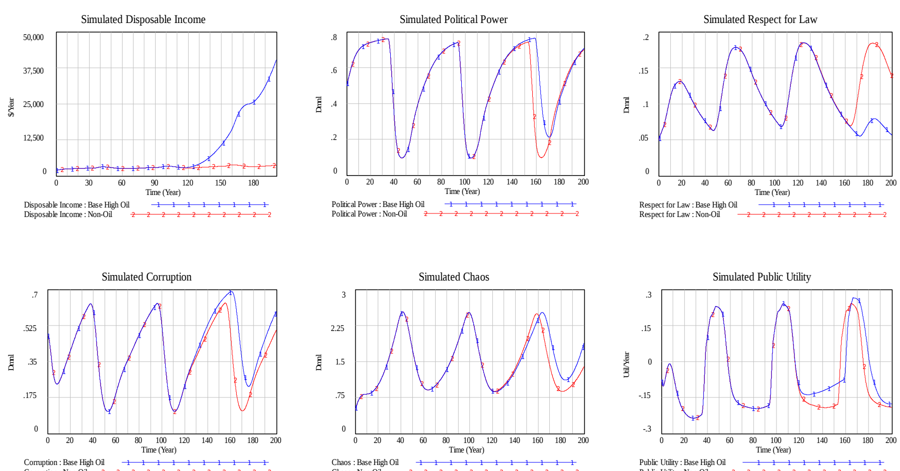

Figure 2.5.4: Simulation results of Katouzian's model (base with tenfold oil revenues vs. non-oil)

claim that although oil revenue may strengthen Iranian despotism, it is not a fundamental cause of it (Katouzian, 1981, pp. 242-243). In terms of the resource curse, these tests appear to indicate that the "curse" does not exist in a "Katouzian world."

2.6 Predictive Scenario Analyses

This section presents the results of three "what-if" controlled experiments tested on the Katouzian model. The goal is to explore the implications of several well-known proposals that are aimed at improving the Iranian socio-political-economic system when applied within a Katouzian framework. The first experiment simulates the consequences of economic sanctions imposed on Iran by Western nations. The second tests "civil resistance" as a means of socio-political transformation—a solution widely advocated by Iranian opposition groups. The third explores the implications of educating the Iranian citizenry so that they develop a higher level of respect for the law. To perform these tests, the simulation time horizon is extended an additional century, i.e., to time 300. The new policy changes are applied in year 200 and their impacts traced over the years 200 to 300.

2.6.1 Economic sanctions

The economics literature is awash with theoretical and empirical contributions that examine the impact of economic sanctions on a nation's socio-political-economic system[29]. Although the majority of the studies conclude that economic sanctions do not work as intended, some scholars believe that they can destabilize a targeted state (Marinov, 2005). In the case of Iran, Amuzegar (1997) believes that US economic sanctions have had meaningful, although not decisive, impacts on the Iranian economy. Fayazmanesh (2003), on the other hand, thinks that sanctions have both harmed the Iranian economy and strengthened the Iranian state. Torbat (2005) has a different view in that he believes economic sanctions have hurt the Iranian economy and had only a modest impact on Iran's political structure.

Given the mixed results in the literature about the effectiveness of economic sanctions, it would be interesting to see what the Katouzian model has to say on the matter. To test economic sanctions, an exogenous limit on Iranian oil exports is introduced into the model in the simulated year 200. Although quite simple, this change captures the overall impact of economic sanctions reasonably well. More specifically, economic sanctions affect the economy through several channels including financial markets, international trade, internal banking, etc.

[29]See for example Hoffmann (1967); Daoudi and Dajani (1983); Nincic and Wallensteen (1983); Tsebelis (1990); Hufbauer et al. (1990, 1997); Elliott and Uimonen (1993); Martin (1993); Morgan and Schwebach (1997); Pape (1997); Cortright and Lopez (2000, 2002); Marinov (2005); Lektzian and Souva (2007); Peksen and Drury (2010); Escribà-Folch and Wright (2010); Bapat et al. (2013).

Fundamentally, however, economic sanctions limit Iran's ability to import intermediate goods (i.e., goods that are used in the production of both consumption and capital goods). This hinders Iran's domestic industries and increases its rate of inflation. Combined together, these impacts reduce the purchasing power of the Iranian people. Given the current level of aggregation in the Katouzian model, however, these effects are captured by a single factor—a significant decline in the government's revenue stream due to a loss of oil revenue. This not only reduces the state's financial resources, but also decreases the total output of the economy. One important impact of a reduction in the government's revenue that is not explicitly accounted for in the Katouzian model is any social unrest that might be caused by higher rates of inflation and/or the relative scarcity of some essential goods such as medicines or specific nutritional products. These effects are simulated in this experiment by an exogenous decrease in *public utility*. A more comprehensive analysis of the impact of economic sanctions on the Iranian socio-political-economic system would require explicit inclusion of all the aforementioned factors, which is a task that goes far beyond the scope of this chapter.

The impact of economic sanctions on the Iranian system of political economy is shown in Fig. 2.6.1. The results of the economic sanctions experiment are named *Sanction* in the time series graphs. The comparative plots in Fig. 2.6.1 show that economic sanctions have a considerable impact on the disposable income of Iranians. They also have a noticeable impact on the behavior of the socio-political system. Although they have shifted the *Political Power* of the state and its stock of *Corruption* downward, they exacerbate socio-political instability by increasing *Chaos* reducing the level of *public utility*, and increasing the frequency of the cycle in *public utility*. The good news, however, is that economic sanctions have increased *Respect for Law*, which might be beneficial in the future.

In sum, the simulation experiment presented in Fig. 2.6.1 indicates that economic sanctions do not appear to be effective in changing the fundamental behavior of Iran's socio-political system. Although they might be able to weaken Iran's economy, they appear to be very costly as they generate higher instability. However, lower average levels of *Political Power* and *Corruption*, along with higher average level of *Respect for Law*, suggest a generally less arbitrary society over time.

2.6.2 Civil resistance

It is widely believed that "civil resistance" can facilitate the democratization of a nation (Chenoweth and Stephan, 2011). According to this belief, citizen activism in form of protests, boycotts, civil disobedience, etc., can separate oppressive regimes from their main sources of power and weaken them over time. Based on this argument, those who oppose the Iranian government frequently encourage Iranian citizens to engage in various forms of civil resistance. As in the case of economic sanctions, the Katouzian model can be used to test the effectiveness of a civil resistance strategy in changing the socio-political-economic dynamics of Iran. This test can be performed by exogenously reducing the model's *Respect for Law* after time 200 and examining the results[30]. Fig. 2.6.2 shows what happens when this change is introduced into the model.

Results clearly indicate that a reduction in *Respect for Law* has no favorable impact on the Iranian socio-political-economic system. It shifts *Chaos* to higher levels and *disposable income* to lower levels, while at the same time generating more overall instability by reducing the period of the system's oscillations. In fact, by encouraging people to disobey the rule of law, Iran's culture of arbitrariness is strengthened. This arbitrariness persists even after the state is overthrown and, through the mechanisms discussed earlier, it undermines Iran's socioeconomic performance in the long run.

2.6.3 Improved respect for law

It is also instructive to look at the problem of Iranian underdevelopment from the viewpoint of the state. To the state, a favorable system is the one that performs well economically while at the same time exhibiting political stability over the long run. Experimentation with the Katouzian model shows that there are few things that the state can do to sustainably improve the future behavior of the system in these areas. The one thing that does seem to work to some degree, however, is to improve Iranian citizens' respect for the law by, for example, investing in primary education so as to strengthen this cultural characteristic in younger generations. In Section 2.6.2, it was shown that a decline in respect for the law can exacerbate Iran's culture of arbitrariness. Thus, it makes sense to check to see if an increase in respect for the law can generate a decline in arbitrariness. Although it might be seen as paradoxical to assume an arbitrary state would fight against a culture of arbitrariness, experimentation with the Katouzian model shows that the state may benefit from this fight. This policy intervention is tested by exogenously increasing *Respect for Law* for 10 years (see *Respect for Law* in Fig. 2.6.3 from time 200 to time 210). This policy can be operationalized by, say, increasing investment in primary education with the focus on the importance of respect for the rule of law. The impact of improving respect for the law by the citizens of Iran is shown in Fig. 2.6.3.

The economic benefits of this policy emerge after a significant delay (about 20 years). *Disposable income* starts to take off at about time 220 and grows significantly faster thereafter. Moreover, this economic growth rate is steadier than the base case simulation. The political system is also more stable as *Chaos* declines significantly, *Corruption* shifts downward and is steadier, and *public utility* is, for the most part, higher and with smaller volatility[31]. It is also

[30] In practice, it is difficult to convince a large percent of a nation's people to engage in civil resistance. Indeed, respect for the law is a cultural characteristic that cannot be changed quickly. Nevertheless, it is still worthwhile to see what would happen if increased civil resistance were to occur in Iran because negative results would indicate that this approach should not be pursued.

[31] Although at first pass this scenario appears to be the "magic bullet" that fixes everything, some caution is in order. According to research by Saeed (1986), high economic growth rates provide the state with financial resources that will mostly be invested in national defense,

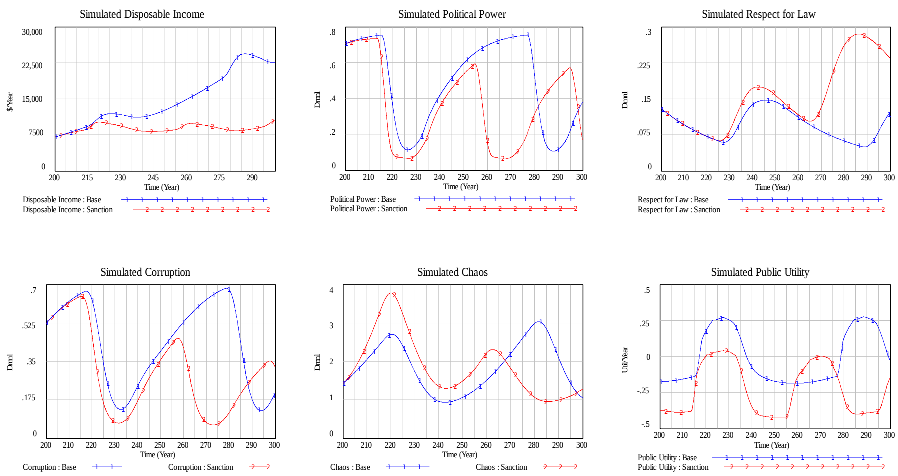

Figure 2.6.1: Impact of economic sanctions on political economy

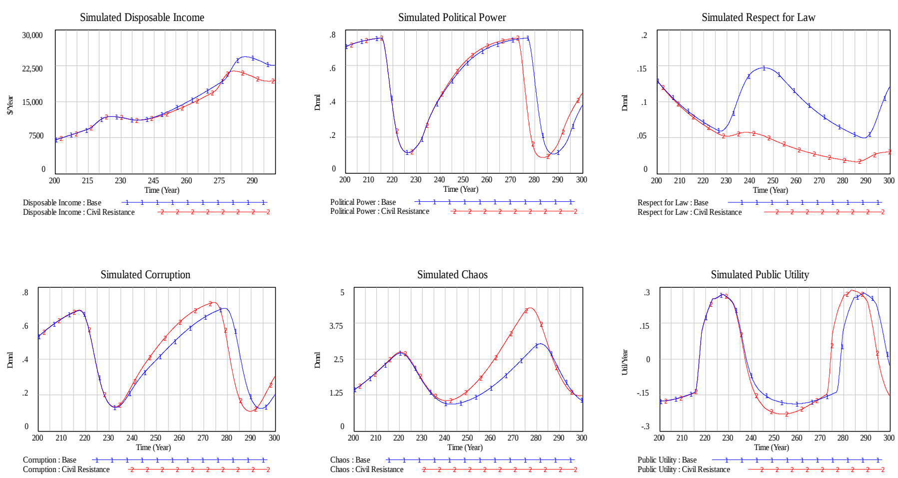

Figure 2.6.2: Impact of civil resistance on political economy

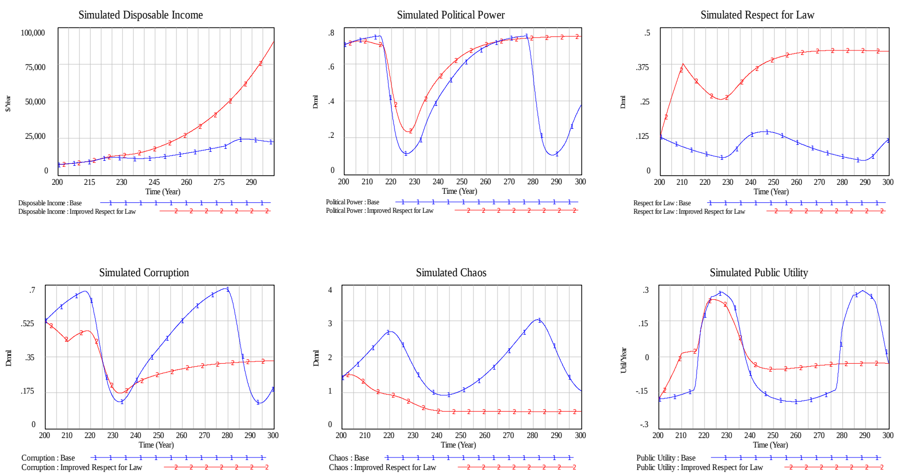

Figure 2.6.3: Impact of policy intervention (improving Respect for Law)

notable that *public utility* remains below zero until the end of simulation, which is mostly due to lower levels of *freedom* since the state is very powerful in this scenario.

2.7 Conclusion

This chapter presents a system dynamics interpretation of Homa Katouzian's theory of Iranian economic development. Katouzian uses a descriptive historical "case study" to explain the origins and causes of the underdevelopment of Iran's socioeconomic system. The model described in this chapter adds value to Katouzian's theory by translating it into a quantitative simulation model that enables it to be formally tested for internal consistency and used for controlled "what-if" experiments and policy analysis.

In terms of building confidence in the Katouzian model, validation tests show that its dynamic behavior is consistent with the qualitative behavior of both Iranian historical data and Iran's socio-political-economic dynamics as described by Katouzian in his theory. In terms of simulation experiments, the effects of both oil revenue and the citizenry's respect for the rule of law on Iranian economic development were examined.

As shown in Section 2.5.1, periodic episodes of significant arbitrary power are key to understanding the historically less-than-optimal behavior of the Ira-

which in turn can hinder future economic growth. This can create a cyclical of political instability that is fairly common in developing countries. It can be a good exercise for the future research to see if the inclusion of the mentioned structure can distort the results of this chapter.

nian socioeconomic system. Simulation results indicate that if Iran was a less arbitrary system, it could experience a greater pattern of economic, social, and political development. The results also show that although oil revenue has had a substantial impact on the economy, it has had little effect on the overall behavior of the Iranian socio-political system. Oil revenue helps the state to accumulate more power but does not change the generic cycle of "arbitrary rule-chaos-arbitrary rule."

Additional simulation experiments examined the impact of economic sanctions and civil resistance on the political economy of Iran. The experiments revealed that, although economic sanctions can influence the economy and weaken the political system, they are ineffective at reforming the long-term behavior of the socio-political system or, even worse, might increase the system's instability.

Civil resistance, which is often advocated by Iranian opposition groups, also was shown to have an adverse impact on the system. More specifically, it was shown to have a negative influence on the Iranian economy, while at the same time reducing the state's power and thus generating more instability in the long-term behavior of the system. In fact, by encouraging people to disobey the law, civil resistance strengthens Iran's culture of arbitrariness. This arbitrariness persists even after the state is overthrown and undermines socioeconomic performance in the long run.

From simulations of the Katouzian model, it was possible to generate some insight into the types of policies that might be effective in improving the dynamics of Iran's socio-political-economic system. The primary finding was that Iran should invest in improving social norms so that its citizens pay more respect to the rule of law. It was hypothesized that this can be operationalized by, perhaps, additional investment in primary education.

The purpose of this chapter was to shed some light on the issue of the underdevelopment of a nation with an unstable socio-political environment using Katouzian's theory of Iranian political economy. Therefore, the boundary of the model was limited to Katouzian's theory of Arbitrary State and Society. The analytical capabilities of the model are thoroughly explored and reported in this chapter. In particular, it is shown that the model—if customized and elaborated appropriately—can be applied to address the impact of socio-political-economic factors such as resource abundance, economic sanctions, civil resistance, cultural transformation, etc., on the system as a whole.

Since the structure of the model presented in this chapter is an interpretation of Katouzian's theory of Arbitrary State and Society, the results of any "what-if" experiments or policy tests are only applicable to a "Katouzian world." As such, care must be taken to not apply them to Iran (or any other family member systems) until a rigorous structural assessment test—considering all available theoretical and experimental sources of knowledge—has been performed on the model. In other words, the Katouzian model would need to be enriched with all of the structural detail necessary to examine any particular issue, irrespective of whether or not the additional structure is directly part of Katouzian's theory, before more general policy conclusions can be reached. The most important structural enrichment that should be added to the current version of the Katouzian model is most probably social and economic inequality, which is likely to substantially influence Iran's socio-political instability. Additionally, a demographic system, labor markets, educational systems, and financial markets are among the subsystems that would need to be added to enable the model to answer additional policy-related questions.

Finally, the results presented in this chapter, even if it is acknowledged that they are only applicable to a "Katouzian world," rest on the assumption that the model accurately and comprehensively captures the richness and uniqueness of Katouzian's original work. Since the model was built by reading Katouzian's voluminous works, identifying the most important factors, and then translating those factors into mathematical equations, the possibility exists that this process was performed imperfectly. In fact, the possibility exists that this process was performed so imperfectly that the model does not accurately capture the salient parts of Katouzian's theory nor does it accurately portray a "Katouzian world." Although care was taken to minimize the possibility of a mischaracterization of Katouzian's views, confidence in the model can only be achieved over time as those familiar with the theory of Arbitrary State and Society examine the model's structure and run simulation experiments of their own.

Chapter 3

A System Dynamics Model for Political Economy of Natural Resource Curse

3.1 Introduction

Resource curse—negative impact of resource abundance[1] on economic growth rate in a national economy—is still an open question in the literature of economic development. Although most papers in the resource curse literature tend to follow Sachs and Warner's (1997; 2001) finding that economic growth is negatively associated with the size of resource abundance in a country, but there is an emerging literature (Brunnschweiler, 2008; Brunnschweiler and Bulte, 2008, 2009; Cavalcanti et al., 2011a,b; Mehlum et al., 2006; Mohaddes and Pesaran, 2013) which argues that not only the so-called resource curse paradox does not exist, but on the contrary, in some situations resource abundance may positively affect growth[2]. Thus, from the empirical literature, there is no clear cut answer to whether natural resource wealth is a "blessing" or a "curse" (Esfahani et al., 2014; Frankel, 2012).

[1] "Resource abundance" in the literature refers to subsoil natural resource wealth. In contrast, "resource dependence" refers to actual extraction and export of that wealth. In this chapter we assume that there is a stock of subsoil natural resource wealth which will be extracted and exported with a given rate. This assumption allows us to use the words "abundance" and "dependence" interchangeably throughout the chapter because "abundance" will always lead to "dependency" in our case.

[2] Variation in the results mainly arises from differences in methodologies and types of data that each study uses. For instance, some studies perform a cross-country analysis while others conduct a panel data analysis. See van der Ploeg (2011) for a comprehensive discussion over this issue.

3.1.1 Problem significance

The question of natural resource curse may seem to be more of a theoretical one rather than to be practical. Nevertheless, its implications have significant influence on real world decisions of policy makers at national, regional, and even global level. As Keynes writes:

> The ideas of economists and political philosophers, both when they are right and when they are wrong, are more powerful than is commonly understood. Indeed, the world is ruled by little else. Practical men, who believe themselves to be quite exempt from any intellectual influences, are usually the slaves of some defunct economist. Madmen in authority, who hear voices in the air, are distilling their frenzy from some academic scribbler of a few years back. I am sure that the power of vested interests is vastly exaggerated compared with the gradual encroachment of ideas . . .. But, soon or late, it is ideas, not vested interests, which are dangerous for good or evil (Keynes, 1936, p. 239).

As Davis and Tilton (2008) point it out, based on the lessons learned from the natural resource curse hypothesis many interventions have been applied to developmental plans of underdeveloped and developing countries aiming at limiting resource extraction simply because it was believed that the revenues from these resources would slow the pace of economic growth down. It should not be difficult to imagine how destructive this policy could be if the resource curse hypothesis was wrong. Resource curse also has significant impact on the global state of socioeconomic welfare. Hypothesized destructive effects of natural resource abundance such as corruption, civil conflict, under-development of economic, social, and political systems, in geopolitically important areas such as Middle East are serious threats to global peace and sustainability. Better understanding of natural resource curse dynamics will be useful to people of resource-rich countries as well as to those who may be directly or indirectly affected by socio-political-economic instability of those countries[3].

The problem is meaningful especially when it comes to major oil exporting countries such as Iran or Saudi Arabia. Having over 157 billion barrels of proven crude oil and 34 thousand billion cubic meters of natural gas reserves [as of 2014] (OPEC, 2015), Iran is one of the richest countries in terms of fossil fuel abundance. Average dependency of the Iranian government to oil export during this period has been about 56%[4]. Total export value of Iran in 2014 has been about 99.0 billion dollars. Oil export has been valued 53.6 billion dollars during the same period i.e. share of oil in total exports of the country has been about 54%. And, this is only a diluted, misleading rate because oil revenue has been declining significantly during recent years due to targeted sanctions. Data that

[3] To learn about negative effects of instability on economic performance of societies see Alesina and Perotti (1994); Alesina et al. (1996); Aisen and Veiga (2013).

[4] This is based on our calculation from formal data published by Iran's Central Bank (CBI, 2015).

Mohaddes and Pesaran (2013) have collected show an average of about 80% for the share of oil in total exports of Iran from 1960 to 2010. Farzanegan (2009) reports this rate to be around 90%. Average share of oil revenues in Iranian GDP, during 1959-2010, has been about 19%[5].

These figures, in general, show a chronical dependency of Iranian economy to oil revenues. Many other resource-rich nations follow similar patterns[6]. Nevertheless, this size of dependency on oil revenues may or may not be beneficial to socio-economic welfare of citizens. While oil revenues could fuel development programs through investment in infrastructure and financing public welfare initiatives such as expansion of free higher education, funding modern health-care systems, improving transportation network, etc., they might also bring with themselves corruption, dictatorship, inflation, destruction of domestic industries, and so on. In other words, the question here is that "are the resource revenues worth it or not?" This is, in fact, the question that this chapter tries to address.

3.1.2 Urge for a fresh look

One important issue with the current literature is the narrow—and sometimes ambiguous—definition of "curse" that is usually employed by researchers. It is naïve to decide that natural resource wealth is "bad" only because it may hinder economic growth. Recent studies in the fields of behavioral economics and psychology has revealed that social utility (happiness) is a more complex function than what conventional macroeconomic models tend to use (Layard, 2005; Frey and Stutzer, 2010).

Another issue is that the current methodologies—mainly econometrics—are inadequate to address such a nonlinear, feedback-rich, and dynamically complex problem[7]. Lucas (1976) argues that econometric models are not accurate representation of the current economic structure, nor appropriate for policy analysis in a dynamic environment. If, for any reason, policies change, economic agents would adjust their behavior accordingly. Econometric models cannot take such feedback mechanism into account effectively. Sims (1980) also believes that macroeconometric models are prone to identification problem and their policy recommendations must be treated with care. Leamer (1983), shows that how prior opinion about a particular identification can distort the outcome of an econometric estimation. He concludes that while econometric approach is effective for experimental analyses, it is not so for non-experimental (natural) settings. But, it is almost impossible to create an absolutely controlled experimental environment to test hypotheses about "natural resource curse" problem in a natural setting over long-term periods. Furthermore, even carefully designed econometric studies could still suffer from lack of reliable data[8]. Un-

[5]See footnote 4.

[6]See e.g. historical data from OPEC (2015) for the case of oil and natural gas.

[7]For a summary of fundamental fallacies of econometrics in addressing socioeconomic problems, see (Solheim, 2005) and (Hollanders, 2011).

[8]Some even believe that measurement of economic variables is not accurate enough for a

reliable data, especially in underdeveloped—-and many developing—-countries, may pervert the results of these analyses (Griliches, 1984; Amuzegar, 1983, 1997). Without reliable data, econometrics will be futile. Quantity of data is also an important limitation for the problem of "natural resource curse" if one wishes to perform a comprehensive analysis. Scale of this particular problem is large and it requires a relatively large system of simultaneous equations. To estimate such a system, considerable degrees of freedom will be lost inevitably. Alternatively, one could estimate a reduced form of the equation system but then the connection between the model and the real world policy space would be broken.

Indeed, the problem of "natural resource curse" is dynamically complex and a systems perspective to the issue is desperately needed. Most of research efforts in this area deploy an static approach by assuming many relevant factors to be constant over time. However, this is not an effective approach. As (Katouzian, 1979, p. 13) writes:

> Other things remaining equal, the oil countries are in the most favourable position for the transformation of their socio-economic entities within a reasonable period of time. But it was postulated that other things are unlikely to remain equal, so that there may be better and worse ways of achieving this; or, indeed, completely missing the boat!

System dynamics—or simulation, in general—seems to be a superior approach for this dynamically complex problem. It allows us to include a large set of simultaneous equations in the analysis without being worried about lost degrees of freedom. System dynamics models generate macro behavior from a micro structure which resolves Lucas' and Sims' critiques (Forrester, 1989). Moreover, reliance of system dynamics—or simulation—models on formal data is not significant. Therefore, lack of formal data in developing countries will not affect the analyses.

But, system dynamicists have paid little attention to this particular problem so far. Although many energy-economy modeling efforts have been made using system dynamics approach[9], there have been only four studies relevant to the problem of "natural resource curse." Ali Naghi Mashayekhi in his Ph.D. dissertation (1978) investigates dependency of the Iranian economy to oil revenues. Erling Moxnes, also in his Ph.D. dissertation (1983), addresses the same issue for the Norwegian economy. Both of these studies are focused on the Dutch Disease as the main impact of resource revenues[10]. Arif and Saeed (1989) address the transition of Indonesia from an oil-dependent economy to one that is

scientific study (Morgenstern, 1963).

[9]For recent reviews of the literature see (Kiani et al., 2010; Leopold, 2015).

[10]Mashayekhi does not include real exchange rates explicitly in his model. So, one may argue that Dutch Disease is not reflected in his work. However, the core mechanism in his theory that—through import of intermediate goods—makes the economy addicted to oil revenues and weakens domestic industries, is considered to be a manifestation of the Dutch Disease theory.

independent of such non-renewable natural resources. Mashayekhi (1998) investigates the dynamics of government financial structure and public services in the course of economic development based upon oil exports. All these models focus exclusively on pure economic factors ignoring socio-political aspect of the resource curse.

3.1.3 Scope

Although purely economic aspects of the problem such as Dutch Disease and volatility of commodity prices are widely investigated, but softer facets of the issue such as socio-political consequences of natural resource wealth are not fully understood. Therefor, this chapter is focused on the socio-political-economic effects of resource abundance[11]. It contributes to the literature by providing a unique comprehensive dynamic model that endogenously captures different facets of the natural resource curse phenomenon in one single package. These facets are:

- **Dutch disease**—appreciation of real exchange rate due to natural resource windfall which eventually leads to deindustrialization of the economy (Corden, 1984; Forsyth and Kay, 1981);
- **Temporary loss in learning by doing** as a result of declining traded sector (Sachs and Warner, 1995; Gylfason et al., 1999; Torvik, 2001);
- **Corruption**—natural resource windfall could corrupt the political system and consequently hinders the economic growth (Ades and Di Tella, 1999; Bourguignon and Verdier, 2000; Acemoglu et al., 2004; Isham et al., 2005). This is particularly significant in nondemocratic regimes (Collier and Hoeffler, 2009);
- **Volatility of commodity prices**—instability of natural resource wealth due to sudden changes in commodity prices or resource discoveries leads to boom and bust cycles (Ramey and Ramey, 1995; van der Ploeg and Poelhekke, 2009, 2010);
- **Rent seeking**—natural resource wealth could encourage rent seeking behavior leading to a less productive economic state (Gelb, 1988; Lane and Tornell, 1996; Auty, 2001);
- **Conflict**—natural resource windfall may lead to socio-political turmoil or even armed conflict (Collier and Hoeffler, 2004; Fearon, 2005; Basedau and Lay, 2009; Lujala, 2010);

[11] We approach the "natural resource curse" problem primarily from a social-political economy point of view and thus, even though we realize that many economists address the problem by way of the "impossible trinity" (Mundell-Fleming trilemma) (Dornbusch, 1976), our model does not include a detailed monetary sector and hence is not able to approach the problem this way.

- **Suboptimal policies**—short-sightedness of state actors causes excessive borrowing, over-generosity in public welfare expenditures, and abuse of resource wealth (Ross, 1999).

In addition, the concept of "natural resource curse" is revisited and a new, more comprehensive definition of the term is provided. Based on the new definition and the explanations provided above a dynamic hypothesis is developed and tested with a large set of Monte Carlo simulations. Simulation results show that the curse is unlikely—not impossible though—to happen in most of socio-political-economic settings. Finally, aggregate level strategies that can mitigate the significance of the resource curse is explored. In this regard, Section 3.2 describes the model structure. Simulation results and model analyses are reported in Section 3.3. And, Section 3.4 concludes the chapter.

3.2 Model Structure

Model that is developed here is indeed an eclectic theory which stands on the shoulder of several other well-established theories. In other words, different pieces of the puzzle are put together to provide a more comprehensive, reliable theory for understanding the dynamics of natural resource curse. It is recognized that economists may address the problem by way of the "impossible trinity" or "Mundell-Fleming trilemma" (Fleming, 1962; Mundell, 1963) However, our model approaches the problem from a social-political economy perspective. Moreover, due to the relatively short-term nature of monetary policies, including them in our system of equations may cause the system to become stiff. Therefore, the model excludes a detailed monetary sector.

This section reveals the model's structure in an aggregate manner[12]. Based on the theories mentioned in Section 3.1.3 a dynamic hypothesis is developed. The most immediate impact of oil export is the appreciation of real exchange rate. This causes a decline in the utility of exports while imports are encouraged. As a result, private sector production of traded goods will stagnate. Higher rates of unemployment force the government to employ unemployed workforce with a greater pace than it otherwise would do. This results in an over-expansion of government sector relative to the private sector. Greater state control over economic resources of the society generates an unusually powerful state which limits socioeconomic freedom. Decline of freedom undermines system of checks and balances, hence, creating a corruption-prone environment. Corrupt governance, weakens domestic production, and lack of socioeconomic freedom ruins economic and political legitimacy of the state and creates sociopolitical unrest. Social chaos discourages private investment and worsens the economic performance. Economic recession declines wage rates that reduces economic power of the middle class. This harms development of the civil society and worsens the problems of corruption and chaos. Higher corruption and chaos, as described

[12]Details of the equations and their references are reported in Appendix C.

earlier, exacerbate the economic difficulties even further. To maintain the declined level of social welfare, government increases public expenditures either as government investment or transfer payments. Overspending in public services pushes the burden on government financial resources and leads to foreign debt which puts stress on the political system. This feeds back to the sociopolitical system and triggers a vicious cycle that could be called the "natural resource curse." However, what is usually underestimated in many natural resource curse theories is existence of balancing feedback mechanisms in social systems. For example, as population of rent-seekers and corrupt government agents increases, rent per capita that could be grabbed by each of them declines. This reduces financial incentives for both current and potential rent-seekers and corrupt agents. Indeed, there is always a limit to growth. Another less appreciated mechanism is the relative growth of middle class power due to expansion of public expenditure, especially through free or low cost higher education provided by the resource revenue. This mechanism helps the process of democratization in the long-term and alleviates some negative aspects of the resource dependency.

Theory that is developed in this chapter includes all of these facets as endogenous components of the model. The only exogenous variable is the volatility of commodity prices. Different scenarios, however, could be tested to capture the impact of commodity price instability. In fact, the emphasis of the model is on socio-political aspect of the natural resource curse problem. As George Soros puts it:

> The resource curse is a complex phenomenon. Three different processes come into play . . ., Dutch Disease . . ., fluctuation in commodity prices and its disruptive effects . . ., and the effect on political conditions. The first two are purely economics and have been studied extensively. It is the third factor that needs to be better understood, especially as its impact is far greater than that of the other two." [George Soros, on the foreword of "Escaping the resource curse" (Humphreys et al., 2007)]

The model consists of 8 modules which dynamically interact with each other, as shown in Fig. 3.2.1. The modules are employment, private investment, government investment, income, price and wage, foreign exchange, [state political] power and control, and oil. "Employment" module determines the allocation of workforce to different production sectors. Resource allocation scheme depends on private and government investment. Capital (calculated in the "investment" modules) as well as labor (calculated in the "employment" module) are main inputs to the "income" module which determines total output of the economy, national income, and its distribution. "Price and wage" module yields the wage rate of the working class as well as price indexes for both traded and non-traded goods and services. Price and wage are then used in the "investment" modules to indicate profit of capital owners. This will affect the private investments. "Foreign exchange" module includes international trade system as well as a simplified international financial market. This module is also responsible for attractiveness of imports and exports. Economic condition, in addition to some other factors, affect the political power of the government which is presented in the "state power and control" module. This module also determines the state's controlling power. The state controlling power then influences quality of governance as well as allocation of resources. "Oil" module includes exogenous scenarios of export of oil. Oil revenues flow into the "foreign exchange" and "government investment" modules to feed the system's dynamics. Following sections look inside of each module.

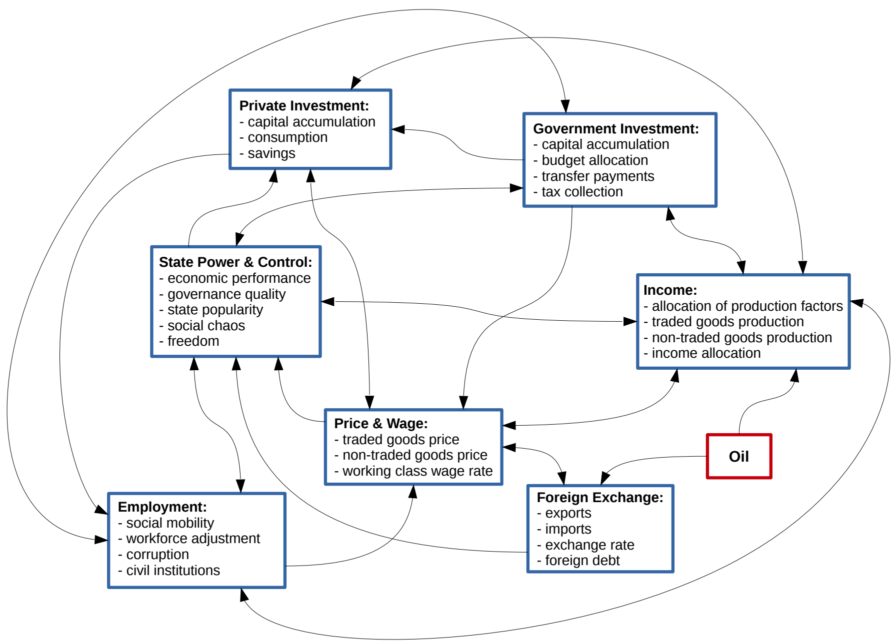

Figure 3.2.1: Overview of the natural resource curse model structure

3.2.1 Employment

There are two major production factors in the model: labor and capital[13] This module is responsible for allocation of labor to different production sectors including private and government sectors.

Three main employment states in the model are: "private workforce," "government workforce," and "unemployed" workforce. This selection is important because first, unemployment needs to be tracked. Second, the private sector

[13]More recent economic growth models usually include other factors such as "education" too. For the sake of simplicity, only labor and capital are chosen to be included in this first version of the model. Future modeling effort could add other factors to examine what difference they can make.

must be distinguished from the government sector for the movement of production factors to the government sector—which is assumed to be less efficient than the private sector—due to greater state political and economic power that is made possible from natural resource wealth could be an explanation of the natural resource curse.

Some theories attribute the natural resource curse to development of corruption and rent-seeking behavior which leads to sub-optimal policies regarding the extraction and export of natural resources (Auty, 2001; Isham et al., 2005). To capture dynamics of corruption and rent-seeking behavior, two additional employment states are included: "corrupt officers"—a subdivision of government workforce that is engaged in corrupt activities—and parasites—a division of workforce population that is engaged in rent-seeking behavior[14]. To control corruption and rent-seeking behavior, societies must strengthen their civil institutions that are the most effective system of checks and balances (Acemoglu et al., 2003; Acemoglu and Robinson, 2005; Mehlum et al., 2006). The sixth and final employment state of the model is "civil activists" as representative of civil institutions. More precisely, civil activities are defined here to be non-profit activities in order to improve citizen's social life and to correct social injustice.

There is no such sharp contrast between different employment states in the real world. If we think of these employment states as fractions of time an individual spends on them, then the deployed division makes sense. For example, a government employee might do his/her job very well and within the boundaries of law but accepts bribes once in a while—say, 1% of the time. A government with 100 of such employees could be represented in our model with 99 persons in the state of "government workforce" and 1 person in the state of "corrupt officers." Same logic applies to the other states[15]. Few of us—if any—might work full-time as a civil activist. A fraction of our time, nonetheless, may be spent on civil activities.

The model starts in equilibrium so none of the employment states change until some exogenous factors disturb the equilibrium—a natural resource windfall is perhaps the best case of disturbance that we could think of. As disturbance occurs, employment states could change in order to reach a new balance. "Private workforce" depends on private investment rate. As the private sector increases its investment, more workforce would be required. The same rule applies to "government workforce" i.e. more "government investment" would require more "government workforce." The government, however, requires human resource for two different purposes: production and control. In addition to its main responsibility (control) the government allocates some of its resources to production of goods and services which could include both public and traded goods and services. Level of human resources the government needs for control depends on the condition of national security. If sociopolitical chaos is significant, the government would need more resources so it tries to recruit more

[14]Saeed et al. (2013) call this division of population as "bandits." "Bandits" do not have a normal job but earn income by participating in illegal, criminal, or corrupt activities.

[15]Another way to think of this division is to consider the content of each employment state as FTEs (full-time equivalents).

workforce. The government decision for hiring workforce is also affected by the government financial situation. A government with limited budget would hire less than a government with ample financial resources would do. Different governments may respond differently to a budget constraint. Some might be more frugal and hence have higher sensitivity to the budget limitations. Others might be more careless in this regard. The model is able to test different policy rules to capture this variation. Fig. 3.2.2 demonstrates an example of such variation in hiring policy by different governments.

Corruption is defined here as an aggregate measure of all sorts of illegal activities practiced by government officials that could lead to distortion of normal distribution of scarce resources[16]. Corruption rate in the model depends on two factors: attractiveness of corrupt activities and transparency. Attractiveness of corruption is assumed to be equal to attractiveness of illegal activities. An incentive for such activities generates incentives for government officials to get involved in corruption. For instance, if there is a considerable stake in drug trafficking then dealers may be willing to offer notable bribes to border patrol agents. All other factors remaining unchanged, likelihood of corruption increases in such cases.

Transparency is another factor affecting the rate of corruption (Kolstad and Wiig, 2009). A transparent society is less susceptible to corruption. Some scholars believe that a broader set of factors aggregated in the concept of "good institutions"[17] are responsible for the magnitude of corruption (Mehlum et al., 2006; Robinson et al., 2014). More generally, "good institutions" help to make better policies. Central banks, for example, are very important social institutions and their decisions may impact consequences of natural resource wealth through the channels described by the Dutch Disease theory. Good central banks may implement policies that help resource rich societies harvest the benefits of natural resource wealth[18]. Magnificence of good institutions, on the other hand, is determined by the level of civil right activities.

Good institutions are developed and maintained by the civil society. Benevolent dictatorship could also help to develop good institutions but those institutions may not last for long if the civil society has not developed to maturity (Langarudi and Radzicki, 2015). Civil activities, nonetheless, could be bounded by level of freedom and economic welfare of the working class. Freedom is an indicator for coercion of the state. High levels of freedom show relatively high tolerance of the government towards the society and its activism. A coercive government limits the space for civil activism[19](Acemoglu and Robinson, 2005).

[16]See Søreide (2014) for a comprehensive conceptual overview.

[17]Good institutions are those social settings which foster socio-political-economic growth while bad institutions encourage rent-seeking and other harmful social behavior (Mehlum et al., 2006).

[18]Central bank policies are intertwined in the "impossible trinity" or "Mundell-Fleming trilemma" but our model does not go into such level of details. The assumption, however, is that "good central banks" pick those combinations of the "trilemma" that have the best short-term and long-term impact on the economy

[19]One may argue that lack of freedom may also encourage civil activism. That might be true if we limit the definition of civil activism to be relevant only to political matters. Nevertheless,

Economic welfare of the working class is important for civil activism. A poor working class struggling with economic difficulties hardly could allocate time and resources to civil activities (Oliver, 1999).

Parts of workforce population become "parasites" depending on how attractive it is to become a "parasite"[20](Saeed et al., 2013). This can happen to any of the employment states explained above but unemployed workforce have more incentives than the employed people to become parasites. Attractiveness of being parasite is an indicator of potential financial gains of getting involved in illegal activities—more on this in Section 3.2.4.

3.2.2 Private Investment

This module simulates the process of capital accumulation in the private sector. It also includes the private sector's consumption. Investment of the private sector depends on availability of financial resources, profitability of production within the sector (discussed in Section 3.2.4), and level of sociopolitical chaos.

Financial reserves are fueled mainly from private savings. A fraction of disposable income will be saved every year and the rest will be consumed. A nonlinear consumption function determines this income allocation process endogenously. Fig. 3.2.3 e.g. shows that how different levels of income could affect the consumption—and thus, saving—under different scenarios. As we will see all these scenarios will be tested in a comprehensive set of sensitivity simulations.

Chaos harms private investment. Here the term "chaos" is defined as unlawful behavior of citizens in all levels of a society. This includes, theft, violence, arbitrary government actions, tax evasion, or any other kind of action that breaks the rule of law. As chaos increases average cost of investment increases which leads to lower rates of investment (Alesina et al., 1996; Dixit, 2007; Haggard and Tiede, 2011; Aisen and Veiga, 2013).

3.2.3 Government Investment

Government investment is a little different from the private investment. Government does not take profitability into account when it comes to investment. Instead, it considers public needs and availability of public funds. Government reacts to unemployment rate as an indicator for health of the economy. For example, Neary and Wijnbergen (1985) describe how the Dutch government responded to high unemployment rates by injecting natural resource revenues into the economy which ultimately led to the "Dutch Disease." As unemployment rises the government increases its investment in order to compensate for

the term "civil activism" here refers to a broader concept that encompasses other areas such as environmental, cultural, economic, and social issues. It is assumed that in presence of a coercive government total "civil activism" becomes less significant, distribution of forces within the body of civil activist community may align towards political issues though.

[20]We define the variable "parasites" as a part of human resources that is allocated to extraction and consumption of the society's resources without contributing to its production or to any engagement that might be harmful—one way or another—for the rest of the society.

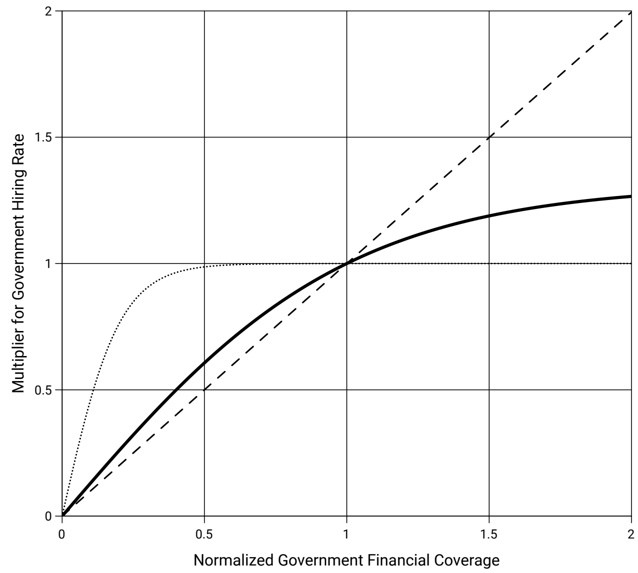

Figure 3.2.2: Effect of government's financial state on its desired workforce

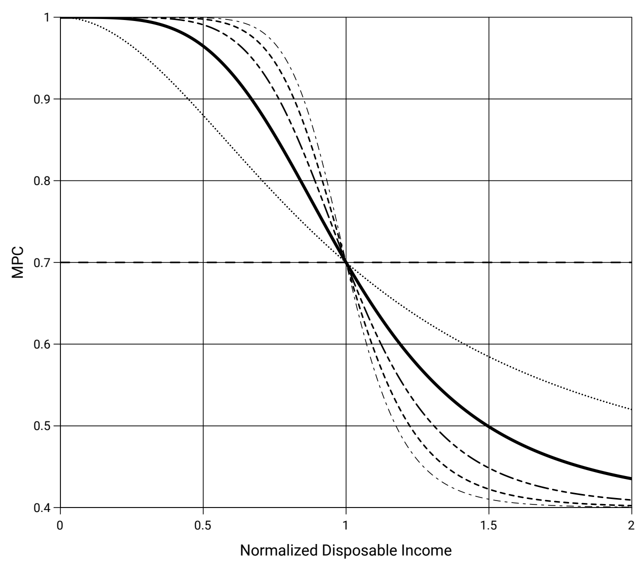

Figure 3.2.3: Marginal propensity to consume under different assumptions

the shortage of private investment. If unemployment rate declines, government funds will be used differently. The module is formulated to provide a wide range of alternative state policies for the case of government investment in response to the unemployment. Fig. 3.2.4 depicts some examples of these alternative policies.

Beside investment, the government has to spend on transfer payments and wages of its workforce. Wage payments will be discussed in Section 3.2.5. It is assumed that governments—particularly in developing countries—increase transfer payments in case of a natural resource windfall. However, they do not react symmetrically when the opposite happens i.e. when government revenues decline for whatever reason (Karl, 1997, 1999). It is because citizens become accustomed to a certain level of consumption and any reduction in that level of consumption could cause a significant decline in public satisfaction which may not be very desirable for any government[21]. Transfer payments mainly depend on availability of government financial reserves. Another factor, however, is the government's perception of its own popularity. If the government realizes that the citizens are not satisfied with the current state of governance, a compensation in the form of transfer payments may be launched (Karl, 1997). Different transfer payments adjustment policies in reaction to popularity of the government could be tested by the provided experimental tools in the model. Some governments might be more responsive while others may be reluctant to change. Although financial restriction may force governments to limit their public expenditures and transfer payments, but it is assumed that higher than normal popularity will not cause a decline in such payments i.e. government popularity might have an asymmetric impact on transfer payments.

Another factor influencing the transfer payments is financial status of the government. Although the government can have budget deficit for short- and mid-term but expenditure and investment must be covered by stream of revenues in the long-term[22]. Government revenues consist of tax and revenues from production of goods and services[23] which includes production and export of natural resources[24].

An important property of a natural resource bonanza aftermath—in particular, for the case of developing (or underdeveloped) nations with democratic political system—is that authorities receiving these revenues spend them to gain short-term political benefits (Robinson et al., 2006). For instance, they cut tax rates, or—as mentioned earlier—increase public expenditures. Thus, tax rate in the model is a function of financial status of the government. If government financial status improves, tax rate declines. The opposite could also happen but a rise in the tax rate does not necessarily translate into higher tax revenues. In

[21] Popularity is particularly crucial for democratic governments in which politicians seek people's votes(Andersen and Aslaksen, 2008).

[22] Despite Post-Keynesian theory of money which relaxes this assumption considering no limit for authorities to issue money (Wray, 2015), we believe that in reality, governments try to achieve—at least a long-run—balance for their budget.

[23] While this may not be significant for capitalist economies, resource-rich developing countries usually have a large government-owned production sector.

[24] Government production is discussed in Section 3.2.4

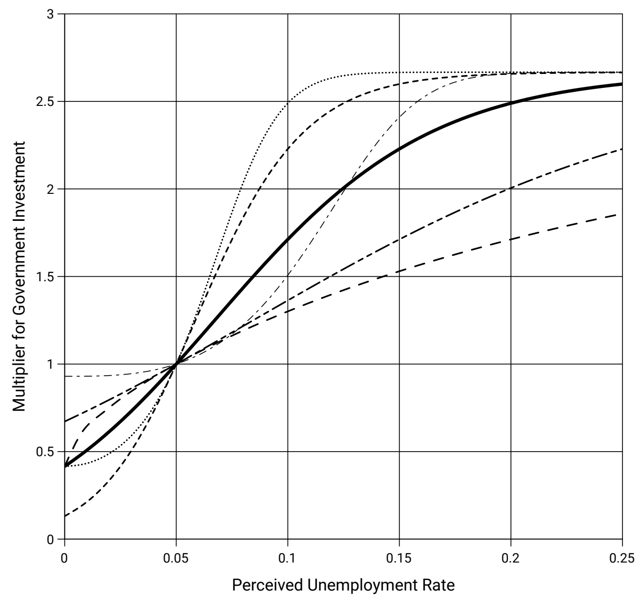

Figure 3.2.4: Effect of unemployment on government investment

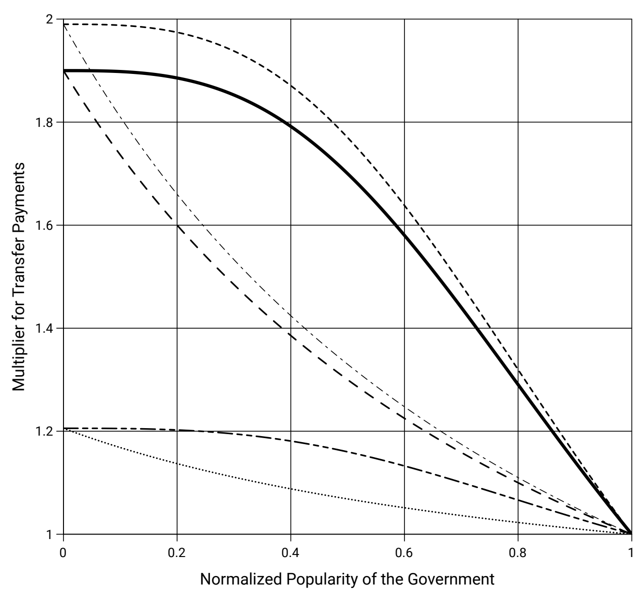

Figure 3.2.5: Effect of government popularity on transfer payments

fact, it requires a powerful, legitimate government to collect taxes (Katouzian, 1997). Again, the model provides a flexible set of tools to examine a wide verity of scenarios and policy approaches in this regard.

Another important determinant of government tax revenues is total taxable economic output. Taxable output includes those economic activities that could be traced and taxed by the government. Underground economy or those activities performed by the parasites are naturally excluded from this definition.

3.2.4 Income

"Income" module calculates production of goods and services in both private and government sectors. It then distributes income and generates a rough measure of income equality. Although income equality might not be a complete measure of equality in general (Allison, 1978), but it is certainly a crucial factor. The goal of this chapter is not to investigate the inequality issues, so, only a simple measure of equality is used here. This sacrifice has been made for compactness of the model. Equality measure in this model is shown by the ratio of wages paid to the working class to total income of the society (wages, profit, and parasite exploitations)[25].

Income of parasites depends on how much they can exploit the economy which is in turn a function of three other factors: (a) availability of economic resources for exploitation, (b) the extent to which exploitation are tolerated (or controlled) by authorities, and (c) level of corruption[26]. As (effective) controlling power of the government increases, parasites will have less freedom to exploit the economy. As economy becomes richer, ceteris paribus, a greater opportunity would be provided for parasites to exploit it. Corrupt government agents have stake in the exploitation of parasites—e.g. through bribes (Søreide, 2014). Therefore, corruption also helps the expansion of exploitation. Finally, natural resource revenues are extra bonus for parasites. According to Karl (1997, 1999), these rents are even easier to be captured by parasites, thus, providing significant incentives for the rent-seekers.

For the sake of simplicity, the only source of income for the capital owners is assumed to be profit from production. Profit is simply the difference between production value and total wage that is paid to the labor. Total output of the economy consists of government and private production given by a Cobb-Douglas function. Goods and services produced in the economy are classified into two categories: traded and non-traded. This is to capture the impact of

[25]For simplicity, it is assumed that wage is the only source of income for the working class while profit is the only source of income for the capital owners. For a more precise computation of income equality, a per capita index must be used. Nevertheless, the model does not trace class population so at this stage it is not possible to have an equality index based on income per capita of different classes. Instead it is assumed that relative population of classes remain, more or less, constant over the simulation period. With this assumption total income of classes could be sufficient to yield a rough approximation of income equality.

[26]The factors (a) and (b) are adopted from Saeed et al. (2013). The factor (c) is added in order to capture the quality of institutions and its impact on political economy of natural resource curse which is one of the most important explanation of the "curse" phenomenon.

natural resource windfall on reallocation of production factors which results in the decline of production of traded goods and service in favor of non-traded goods and services. Relative price indexes in traded and non-traded sectors determine the fraction of production capacity that must be allocated to each sector.

One important aspect of the Dutch Disease theory which has been particularly highlighted in the system dynamics literature (Mashayekhi, 1978; Moxnes, 1983) is that a reallocation of resources from traded goods to non-traded goods sector could significantly harm the economy due to the lost experience in the production of traded goods. This is one of the explanations for the natural resource curse (Gylfason et al., 1999; Torvik, 2001; Sachs and Warner, 2001) and a simple mechanism of experience accumulation/decumulation is employed to capture it.

Finally, the more the parasites earn the more attractive it becomes for others to follow their footsteps (Saeed et al., 2013). The attractiveness of such activities including rent seeking could be given by the comparison between parasite income and average income earned by the working class.

3.2.5 Price & Wage

"Price & Wage" is the module that yields wage rate of the society's working class as well as prices of goods and services. Wage rate is affected by unemployment rate which is used as a proxy for the labor demand-supply ratio. As unemployment increases wage rates decline. In contrast, a decline in unemployment rate puts pressure on wage rates to increase. These adjustments happen after a delay though. All sorts of wage stickiness could be examined in the model.

This module also includes the mechanism of changes in price index in two markets: traded and non-traded goods and services. This mechanism which takes a delay is based on a supply-demand ratio and is similar in both markets. Different scenarios for price stickiness could also be applied.

Demand is a simple equation based on Keynesian national accounting including non-oil exports (only for traded goods and services), private and government investment, and consumption. Supply of goods and services includes domestic supply. This also includes imports for traded goods.

3.2.6 Foreign Exchange

Foreign exchange rate could be affected by many political and economic factors. Mashayekhi (1991), particularly, examines the dynamics of foreign exchange in an oil exporting country. In our model, however, the main factor influencing the exchange rate is the balance between supply and demand of foreign exchange in the domestic economy. Any other factor will be exogenous according to the model's boundary so must be excluded from the analysis. Stickiness of foreign exchange rate could also be implemented in the model.

While imports and other international payments create demand for foreign exchange, exports and other international earnings constitute foreign exchange supply. An appreciation (depreciation) of real exchange rate encourages (discourages) imports and discourages (encourages) exports. International trade is also limited by trade capacity. International trade requires various types of transportation infrastructure including harbors, airports, transit highways, etc. as well as facilities such as border customs and trade institutions. These take time to develop. In addition to trade capacity constraints, adequacy of foreign exchange reserves impose limitation on imports.

According to Mashayekhi (1998), societies could become accustomed to certain levels of imports. While dependency to imports could expand easily, it would be relatively difficult to reduce that level of dependency.

Finally, if the country is short of foreign exchange they can borrow from international financial markets. Nevertheless, interest must be paid on the funds that are borrowed. These funds add to the foreign exchange reserves, so that imports or other obligations could be financed. Borrowing depends on availability of foreign exchange and on the level of debt. If the availability is low, the country borrows more and vice versa. High level of debt is another limiting factor. As the level of debt increases it becomes more and more difficult to borrow. It is assumed that interest rate in international markets is constant. Of course, it is not constant in the real world. However, factors that affect this rate are outside of the model's boundary. Thus, its inclusion only adds to the model's complexity but not much value to our analysis.

3.2.7 State Power & Control

"State power" module computes magnitude of the political power that is controlled by the government. This is an index between 0 an 1 where 0 represents no political power at all while 1 represents absolute power of the government. State power depends on popularity of the state and utility of political power in the society. It also depends on controlling power of the state. These assumptions should be adequate for representing democratic as well as non-democratic political systems. Elasticity of political system, frequency and pace of political change, all can be modified exogenously to test different situations. In fact, this module of the model can take a wide range of assumptions in order to fit different political agendas.

Government here could be a ruling individual, family, tribe, or party. The model does not distinguish between different rulers at different times and places because individual characteristics of the ruling class is not of importance for the analysis of this study. In other words, form of the state does not matter. Rather, its political power matters the most. Consequently, simulation results do not show explicit competition between political parties. It only shows dynamics of incumbent ruler's political power which is called here as "state" or "government" interchangeably.

According to the Katouzian's theory of arbitrary state and society (Langarudi and Radzicki, 2015), popularity of the government provides it with the opportunity to gain more political power. So, higher state popularity makes a political rise more likely. Utility of political power is another factor affecting the state power. As symptoms of social chaos, say crime rates, increase in a society, utility of a powerful government who could control the chaos increases[27]. This could generate a space for the government to seize more power. Chaos works as a double edged sword, though. Beside its positive impact on the utility of power, it could reduce political power by damaging political legitimacy of the government, and hence undermining its popularity. Controlling power of the government is also important to protect its political power. A government with significant controlling power could stay longer at helm. Finally, it is assumed that foreign debt increases pressure on the government and reduces its domestic and international negotiation—and thus, political—power (Thompson, 2007; Dyson, 2014).

Chaos is an indicator of arbitrariness in the society (Katouzian, 1997). Here chaos is defined as any form of activity that breaks the rule of law in a society or any phenomenon that considerably undermines the social order. Chaos in the model depends on population of people who may break the rule of law. That includes parasites and corrupt government officers. If their population increases, chaotic incidents become more likely to happen. The state popularity also plays a role in chaos. A less popular state is more likely to experience chaotic behavior of citizenry (Katouzian, 1997).

Popularity of the state originates from a function that tracks performance of the government. If a government fails to function at a reasonable level, its popularity declines. Good governance should maintain social welfare and security (Wolff, 2006). Classical political philosophers like Bentham and Mill believe that people should expect the government to provide the public good which consists of these elements: providing subsistence, producing abundance, favoring equality, and maintaining security (Held, 1990, p. 24). Classical macroeconomics, in contrast, is founded on an implicit premise that social welfare function includes only inflation and unemployment. As we will see in Section 3.3, based on recent advancement in sciences such as behavioral economics and psychology, the model here assumes more components including freedom, justice, income equality, consumption, public safety and security, and leisure. Here, the government performance is divided into two broad categories: economic performance and political performance. These are not indicators of actual performance of the state but rather perception of the public of how the government is performing. This perception may be right or wrong.

Economic performance of the government consists of three different elements. First element is unemployment. Government, especially in the resource-rich countries, is expected to lead the national economy towards full employment. Any unemployment rate above the natural level would cause social discontent. Second element affecting the image of the state popularity is the real consumption. Government can change level of consumption in the society through trans-

[27] Many political philosophers believe that the most crucial function of the state is to provide safety and security for its subjects and to ensure protection of all things held within its territory (Held, 1990).

fer payments or other public expenditures and investments. In a real-world case this can also contain a wide variety of public services such as health, education, etc. Considering the model's level of aggregation, all these government expenditures are reflected in the real consumption per capita. At the same time, this variable represents the effect of inflation too. As prices increase, real consumption declines, ceteris paribus. Subsequently, economic performance of the government declines. People either compare their situation with their past or with others' situation (Frey and Stutzer, 2010). So, the next element is income equality. A decline in equality negatively impacts social welfare (Easterlin, 2001; Oishi et al., 2011) and thus, ruins the state popularity.

As mentioned earlier, providing peace and safety is considered to be the most important political functionality of the government. Freedom must not be sacrificed though. In fact, the government needs to control chaos for maintaining public satisfaction but this control should not reduce freedom since it is a crucial factor affecting happiness of the society (Frey and Stutzer, 2000, 2010), otherwise, the governance quality declines. The perception of security, freedom, or any other political performance measures could adapt to new circumstances (Frederick and Loewenstein, 1999; Frey and Stutzer, 2010; Saeed et al., 2013). Hence, political performance is a comparison of current and remembered level of governance quality.

A positive interpretation of political freedom is used here to define the term "freedom" as free exercise of social and group political rights without the fear of coercion or oppression[28]. From this perspective, freedom is mainly constrained by the coercive force of the government, thus negatively related to the state controlling power. However, a powerful government does not necessarily limit freedom. The coerciveness of the government could be affected by the extent to which it relies on taxes as a source of revenue. A government with considerable revenues from external sources such as natural resources is less reliant on—thus, less accountable to—the public (Ross, 2001, 2008; Acemoglu and Robinson, 2005). The significance of each of these effects might differ for different political systems. The model provides tools to capture these differences.

Controlling power of the state is a function of the government's share of the society's resources. The more the government owns of total resources of the society the more powerful it becomes. This power is also affected by the government decision on how these resources are used. The more the resources are allocated to control (vs. production) the more controlling power the state would have.[29](Saeed et al., 2013). Political power of the government is another crucial factor to determine controlling power of the state. A government without effective political leadership will not be able to elicit full potential of its controlling resources (Held, 1990).

The way the government allocates its resources is based on comparison between its own economic and political performance. If political performance is relatively low, i.e. (based on our definition) government is not very successful

[28]see Berlin (1990) for a philosophical discussion on the issue.

[29]Only non-corrupt government workforce contribute to the control resources.

in maintaining stability, peace, safety, and security, then more resources will be allocated to control. In contrast, if economic performance is relatively low, less resources will be allocated to control which means that more resources will shift towards production[30].

Receiving feedback from the society to evaluate the state performance is a challenge per se. It is not uncommon that governments fail to perceive the situation correctly, and at best, they perceive it with a delay.

3.2.8 Oil Export

Oil export is selected to be exogenous in the model so that controlled scenario analyses become possible. All sorts of scenarios could be applied to this variable in order to test the model. The following scenarios are included in the default version of the model:

- base case—a S-shape behavior over time for oil export.
- cycle—an oscillatory oil export representing an unstable resource revenue case;
- bell—a bell-shape oil export representing a temporary resource revenue case; and
- flat—a constant (stable) level of oil export.

Fig. 3.2.6 illustrates these scenarios. Functions that are used in the oil module to replicate these modes of behavior are flexible to a great extent so that a wide verity of scenarios could be examined.

The only difference between these cases is their behavior over time. All of them generate an equal amount of accumulated revenue at the final simulation time ($t = 100$):

$$R = \int_{t=0}^{t=100} \alpha Y_0 dt = 100\alpha Y_0 \quad (3.2.1)$$

$$0 \leq \alpha \leq 1 \quad (3.2.2)$$

$R =$ accumulated oil revenue

$Y_0 =$ normal (initial) GDP

$\alpha =$ resource dependency parameter

In equation 3.2.1 α represents the level of resource dependency. Base value of this parameter is 0.4 but it varies randomly in the simulations between 0 and 1 so that a wide range of dependency scenarios could be tested.

[30]This government resource allocation mechanism is adopted from Saeed (1986).

3.3 Results

The model presented in this chapter is a generic theory of natural resource curse. It is not customized for any of the real world cases. All the inputs are hypothetical but mainly rooted in the literature. To build confidence in the model's outputs, it has been subject to most of the conventional system dynamics validation tests[31]—including boundary adequacy, structure assessment, dimensional consistency, parameter assessment, extreme condition, integration error, behavior reproduction, behavior anomaly, and surprise behavior test. The current model can pass these tests successfully[32]. To deal with the uncertainty regarding the numerical value of inputs, all experimentations have been conducted through Monte Carlo simulations with 5,000 simulation runs per experiment. Most of the model parameters including those responsible for shape of the functions have been varying simultaneously with a uniform distribution function during the simulations. As reported in Appendix B, wide ranges of variation are selected for the parameters so that almost all situations that could possibly happen in a real world case are replicated.

3.3.1 Curse or Blessing?

The main goal of the chapter is to answer the questions of natural resource curse. Does it exists? How can it be controlled? To have a meaningful discussion around these questions we first need to agree upon a precise definition of natural resource curse. Classic definition of natural resource curse is the negative correlation between natural resource abundance and economic growth rate (Sachs and Warner, 1995). And that is a static picture of reality. However, this definition seems to be inadequate, particularly for a systems perspective of the issue which is also dynamic. In fact, economic growth rate is not a sufficient measure of social well-being and happiness (Easterlin, 1974, 1995; Blanchflower and Oswald, 2004). Thus, here we take a more inclusive social utility measure (U) which could paint a clearer picture of a socio-political-economic "curse" or "blessing."

Jones and Klenow (2016) advocate a social utility function that includes "mortality," "consumption," "leisure," and "inequality." Our model takes "inequality" and "consumption" into account explicitly. "Mortality" could not be accounted for explicitly because population growth is outside of the model's boundary. However, "chaos," "unemployment," and "consumption," which might affect "mortality" directly or indirectly are included in the social welfare

[31] There is a comprehensive list of confidence building tests for system dynamics models which have been developed over years. See e.g. Forrester (1973); Mass and Senge (1978); Peterson (1980); Forrester and Senge (1980); Sterman (1984); Barlas and Carpenter (1990); Barlas (1996); Oliva (2003).

[32] Some of the confidence building tests such as, dimensional consistency or integration error, could be performed by the automated features of modern system dynamics software packages like Vensim, Stella, etc. Other tests have been conducted as the major part of model development. In fact, the current model has gone through about a hundred revisions each of which aimed at resolving issues that had been arisen due to the confidence building tests.

measure. “Leisure” also cannot be addressed explicitly because the model does not follow the time allocation of individuals. Instead, share of private sector in the labor market is used as a proxy to account for the magnitude of “leisure.” The private sector is the most productive force of the model so, it is reasonable to assume that the more the society’s production factors are concentrated in this sector the less “leisure” time they would have to enjoy. Therefor, “ratio of private sector workforce to total population” enters the social welfare measure as a negative factor. According to recent literature on the concept of happiness [e.g. Layard (2005)] the social utility measure could also include less tangible factors such as “justice” and “freedom.” “Freedom” is an explicit factor in the social utility measure while “justice” is represented by “freedom,” “inequality,” and “corruption.” In fact, the social utility measure in the model is an integration of utilities gained from income equality, freedom, real consumption per capita, employment, safety and security, justice, and leisure. The utility measure u_t at each point of time is a weighted average of these qualities:[33].

[33] To get the final value of average total utility over time, we integrate over all the u_ts, so basically, a lot of utility in one period compensates people for very little utility in another period. It may appear that the society has no preference for a consistent level of utility over time (known as “consumption smoothing”). In fact, they do but the way this is modeled here is different from the way economists usually do it. The model does not assume utility maximization i.e. consumers do not try to maximize their ultimate utility simply because its value is not known. That is, individuals do not know about the U which is accumulated utility of the society at time 100. This is consistent with what happens in reality. Economists usually assume people follow the utility maximization behavior only because of methodological limitations. In contrast, resource allocation problem in system dynamics models is usually addressed by goal seeking mechanism. For example, the government expenditure is controlled in the model by a factor named, “government reserve coverage.” This is basically a time constant that indicates how far ahead a government plans for the economy. If the financial reserves are at low levels the “coverage” time would be low meaning that fewer years in the future could be covered considering the current level of reserves, revenues, and expenditures. This coverage time then will be compared with the standard the government has. If this is lower than the standard then the expenditures must be controlled more strictly or revenues must be increases—borrowing from outside is also a possibility. This way, the consumption between now and future will be smoothed.

$$U = \int_{t=0}^{t=T} u_t dt \tag{3.3.1}$$

$$u_t = \frac{w_c c_t}{c_0} + \frac{w_n n_0}{n_t} + \frac{w_q q_t}{q_0} + \frac{w_p p_0}{p_t} + \frac{w_f f_t}{f_0} + \frac{w_h h_0}{h_t} + \frac{w_r r_0}{r_t} \tag{3.3.2}$$

$$0 \leq w_i \leq 1 \tag{3.3.3}$$

$$\sum w_i = 1 \tag{3.3.4}$$

$i = c, n, q, p, f, h, r$

$U =$ accumulated social utility

$u_t =$ social utility at time t

$c_t =$ real consumption per capital at time t

$n_t =$ unemployment rate at time t

$q_t =$ income equality index at time t

$p_t =$ share of private sector in total employment at time t

$f_t =$ level of freedom at time t

$h_t =$ level of social chaos at time t

$r_t =$ level of corruption at time t

$w_i =$ weight of factor i in the social utility function

Note that the utility measure is not discounted over time. This is because function of u_t is not for individual decision making in the model. It only serves as a measure that will be used by the observer (model user) to make judgment about the model's performance under different scenarios. To have a fair judgment one should not discriminate between past, present, and future. All time periods must be valued equally.

To answer the question of "natural resource curse" we compare simulation runs that include natural resource wealth with those that exclude such wealth. Accumulated social utility yielded from a simulation run that includes oil revenue is shown by U^o while accumulated social utility yielded from a simulation run that excludes oil revenue is represented by U^z. In equilibrium no oil wealth is included, so $U = U^z$. In addition, each of element of the social utility measure is normalized to 1 at the equilibrium state. Thus, $u_t = 1$ at any period of time. Since the simulation time period is 100 years, final value of the average utility ($U = \int_0^{100} U_t dt$) is equal to 100 in the equilibrium state (i.e. $U^z = 100$). Other features of the initial setup that produces the equilibrium state is as follows[34]:

- productive forces = 80%
- corruption = 5%,

[34]Full documentation of the model along with the initial values of parameters is included in the Appendix. Here, we only focus on qualitative interpretation of different settings.

- illegal activities = 5%,
- good institutions = 50 (normal)
- no oil revenues.

This "equilibrium" case represents a normal society without any outstanding resource revenues. How does natural resource revenue affect the equilibrium then? To answer this question we compare U^z (accumulated social utility in a zero oil scenario) with U^o (accumulated social utility in a oil scenario). In this regard a normalized index is defined as follows:

$$\rho = \frac{U^o - U^z}{U^z} \tag{3.3.5}$$

For any simulation run, if ρ is positive, then we can argue that resource revenue is a "blessing" for that particular simulation. Otherwise, that simulation result could be considered as a manifestation of "resource curse." Since U is constant ($U^z = 100$) for all the equilibrium state simulation runs, this comparison would be easy because we only need to compute U^os.

Four different scenarios for the case of oil revenue have been defined as explained in Section 3.2.8. Monte Carlo simulation is performed for each of these scenarios and outputs are analyzed. For each scenario a set of 5,000 simulations are conducted. Each simulation has a unique set of parameters that is randomly chosen. These random sets are reproducible since they are generated from a given seed by the software. For each simulation run U^o and thus, ρ is computed.

Results revealed that most of the simulation runs resulted in a "blessing" (i.e. $\rho > 0$). Fig. 3.3.1 shows histograms of simulation runs that produce different levels of ρ. From 5,000 simulation runs that are conducted for each scenario only few occurred to produce a result worse than equilibrium showing a case of natural resource "curse," that is $U^o < U^z$. More precisely, percentage of simulation runs with $U^o < U^z$ is 0.02%, 0.20%, 1.02%, and 0.60% for S-shape, bell-shape, cyclical, and flat scenarios of oil revenue respectively. This shows that natural resource revenue could hardly be a "curse." This also shows that the cyclical oil revenue—among others—is the most likely case to cause a natural resource "curse." It is in compliance with the commodity price volatility theory of natural resource "curse."

Detailed dynamic behavior of the model reveals some interesting points. Fig. 3.3.2 shows components of the social utility measure over time for the case of cyclical oil revenue. Results show that natural resource revenue could cause a "short-term social curse." Until the year 5-10, social factors of the utility function (the top row diagrams) are reflecting a situation that is worse than the equilibrium state. "Chaos" and "corruption" increase while "freedom" declines. This is consistent with the most recent literature that asserts natural resource wealth corrupts social systems. It is, nevertheless, very likely that problems of chaos and corruption are mitigated (relative to the equilibrium state) in the

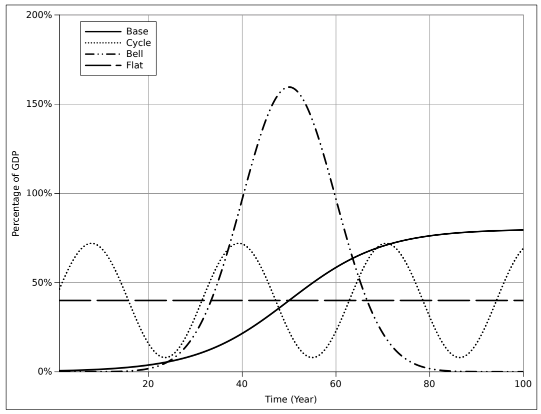

Figure 3.2.6: Different scenarios of oil revenue

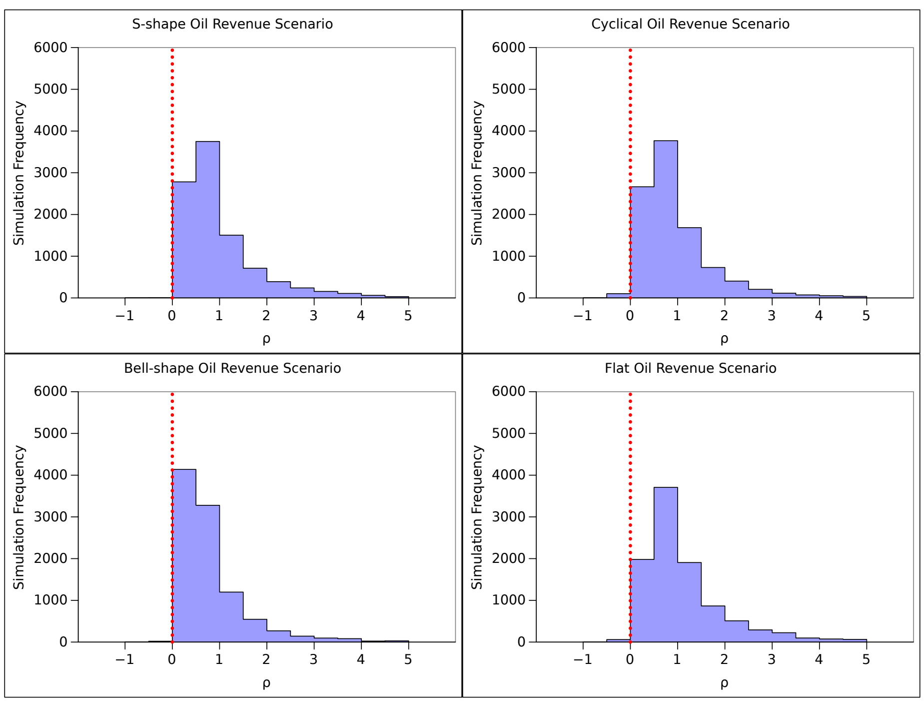

Figure 3.3.1: Histograms of simulation runs with different levels of accumulated social utility

Table 3.3.1: Initial setting of the model (base vs. low institution)

Setting	Base Case	Low Institution
productive forces	80%	75%
corruption	5%	10%
illegal activities	5%	10%
good institutions	50	45

long-term[35]. This finding is consistent with studies that employ a historical (long-term) perspective. For instance, Katouzian (1981) argues that oil revenue is not a fundamental cause of social problems in the long-run, at least for the case of Iran. Simulation analysis of the Katouzian's theory corroborates this argument (Langarudi and Radzicki, 2015).

These results are achieved with a particular initial specification which was mentioned earlier. Nonetheless, institutional theories of natural resource curse suggest that initial condition of a society significantly affects resource-base development patterns (Acemoglu et al., 2003; Bulte et al., 2005; Mehlum et al., 2006; Luong and Weinthal, 2006, 2010). It is almost a common wisdom now that natural resource wealth could become a "curse" in societies with bad institutional and societal settings. Bad institutional setting here means a social system that hinders growth by encouraging rent-seeking and corrupt behavior (Mehlum et al., 2006). In order to examine this claim an experiment is designed and tested. The aforementioned initial societal setting is altered as shown in Tab. 3.3.1. The new case is called "low institution" and has lower productive forces, greater levels of corruption and illegal activities, and lower number of good institutions.

Will natural resource wealth exacerbate the situation—in contrast to a non-resource-wealth case—with this new setting? To answer this question the Monte Carlo simulations are repeated for the "low institution" case, once without oil and once with oil revenues. Since the initial composition of workforce is changed, initial equilibrium no longer exists. Thus, U^z will not be 100 at the final simulation time. Therefore, more computations are needed for the analysis. As mentioned earlier, parameter set of each of the 5,000 simulation runs is reproducible, thanks to the given computer random seed[36]. Each run is performed twice, once including resource wealth (yielding U^o), and once excluding resource wealth (yielding U^z). Then, ρ is computed for each of these 5,000 simulation pairs. Fig. 3.3.3 summarizes the outcome of our experiment.

Again, majority of simulation pairs in all cases of oil revenue (S-shape, bell-

[35]Long-term here means any time frame longer than 60 years.

[36]Random distribution function of the simulation software we use (in this case Vensim DSS) can take a given random seed and hence all the parameter sets generated for the Monte Carlo simulation could be easily replicated. As a result, every simulation run across different oil revenue cases has exactly the same parameter set and hence, absolutely comparable.

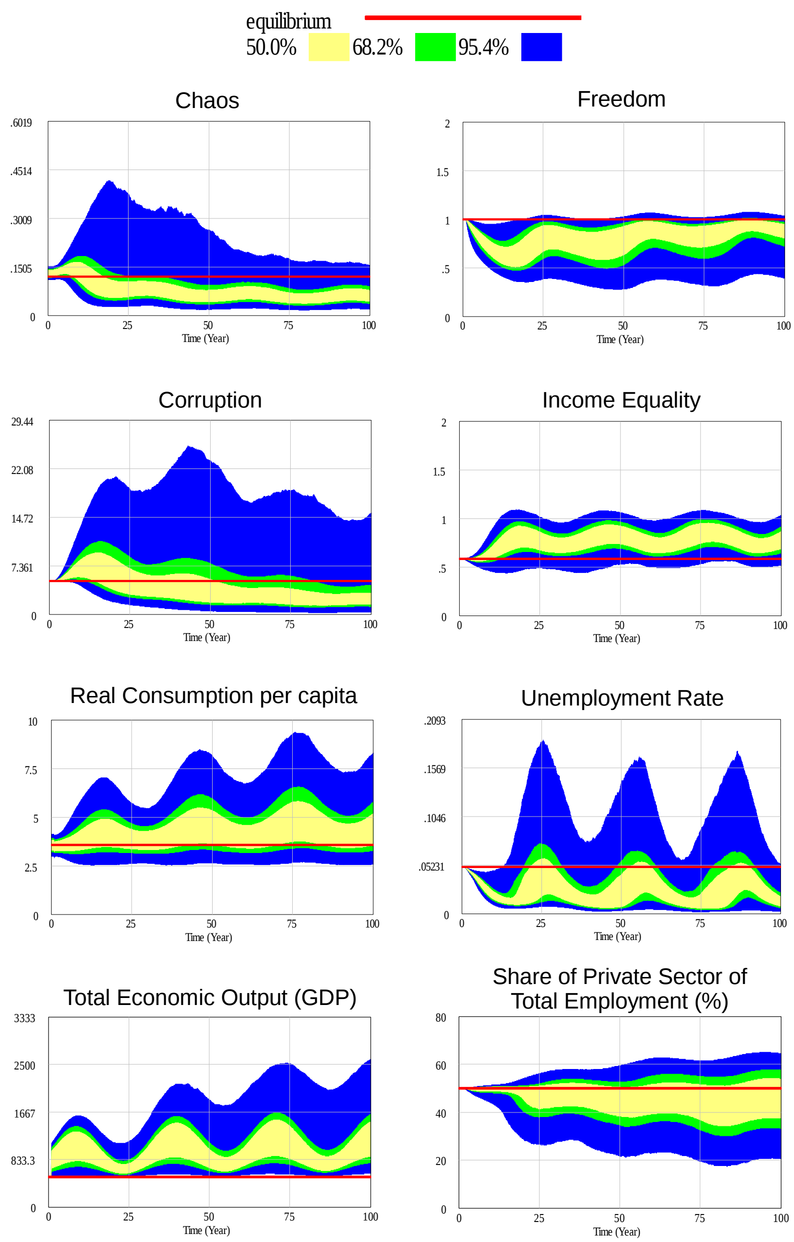

Figure 3.3.2: Simulated time series of components of the social utility for the case of cyclical oil revenue

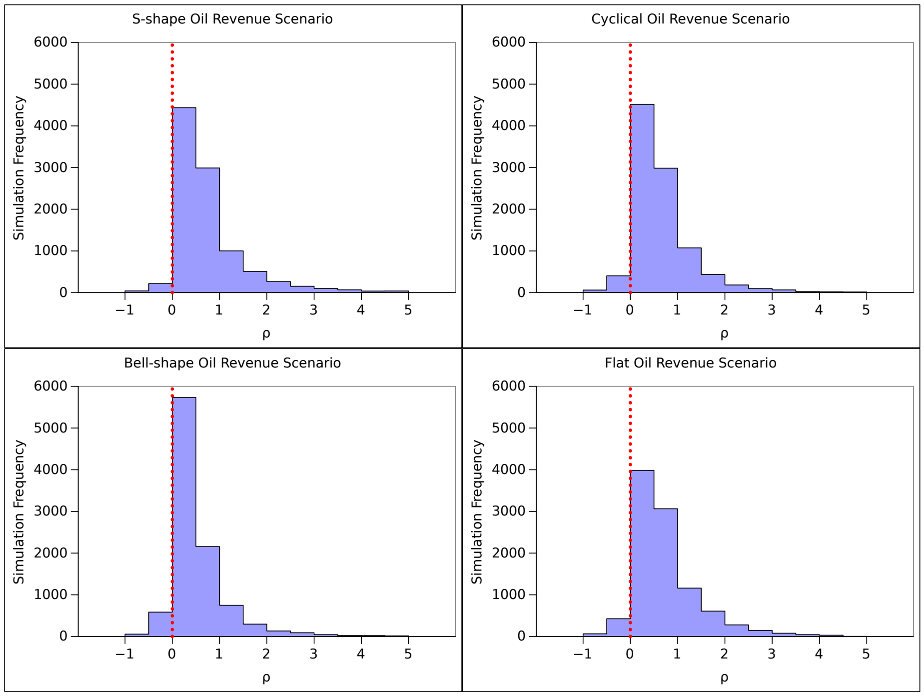

Figure 3.3.3: Distribution of simulation runs for the case of lower initial social setting for different oil export scenarios

shape, cyclical, and flat) generate a positive ρ. Only 2.59% of simulation runs (for the S-shape oil case) generate a U lower than the one in the non-oil case. This figure has been 6.44%, 4.69%, and 4.92% for the cases of bell-shape, cyclical, and flat oil revenues, respectively. In other words, chance of natural resource wealth to cause a "curse" is narrow. This chance increases slightly when resource revenue is temporary (bell-shape) which attests to Robinson et al. (2006) who claimed that temporary natural resource revenue does worse than a permanent one.

As mentioned earlier, oil revenue is also a varying parameter—in terms of a fraction of normal (initial) domestic economic output—in our Monte Carlo simulations. It would be interesting to see how the accumulated social utility is affected by different levels of oil dependency. Fig. 3.3.4 shows this for different oil scenarios. Diagrams on the left column depict the results for the normal model settings while the right column diagrams show the results for the "low institution" settings. Positive correlations between U and "oil revenue" confirm the aforementioned finding that natural resource revenues is more likely to be "blessing" than being a "curse." The intriguing result, however, is that like other (normal) goods—or even individual income—natural resource revenue complies to the rule of diminishing marginal utility. In fact, resource revenue is good, but more of it does not add much to the social utility.

Most papers in the literature take "economic growth" as the main indicator of "curse" or "blessing." Even those who consider other factors such as "corruption," or "freedom," do so because they assume these factors directly or indirectly affect "economic growth." Thus, it would be interesting to see what our model has to say about the impact of resource wealth on "economic growth." Will the result change if we dismiss our comprehensive performance measure? Answer is "no." Effect of oil revenues on average GDP growth rate is illustrated in Fig. 3.3.5. As before, left column presents the results with "normal" model settings while left column diagrams show the results when the settings are set to "low institution." Positive correlation between GDP growth and oil revenue exists in all the diagrams.

3.3.2 Leverage Points

The preceding section showed that deterioration of socio-political-economic condition of a nation due to natural resource abundance is an unlikely case to happen. Does it mean that we cannot improve the situation then? The answer is "no," but it is not an easy task. A comprehensive experimentation with the model under different conditions (parameter sets) revealed that the system is behaviorally insensitive to most of policy interventions. Here, few leverage points that were discovered through experimentation are discussed.

Stabilizing wage rates

One of the model leverage points is the wage stickiness. Wage stickiness refers to the speed of wage adjustment in response to changes in the labor market. High (low) wage stickiness means that wages adjust relatively slowly (quickly) to any disturbance in the labor market. Fig. 3.3.6 depicts the accumulated social utility against the wage stickiness which varies between 0 (no wage stickiness at all) and 0.8 (80% wage stickiness)[37]. Results for the case of "normal" initial social condition are shown in the left column of Fig. 3.3.6 while the right column shows the results for a "low institution" setting.

As we can see, higher wage stickiness generate greater accumulated social utility. One can imply from this outcome that wage stabilization might be a good policy to enhance resource-based development. The reason why this is happening in the model follows this feedback mechanism: natural resource revenue inevitably strengthens the government sector relative to the private sector. The government investment is not affected by the wage rates. Thus, employment rate increases. Higher and more stable wage rates (largely because of natural resource revenues) improve economic welfare of the middle class which leads to their higher participation in civil activities. This helps the good institutions to develop and the corruption to be controlled. Increasing and steady wage rates also reduce parasites' incentives to exploit the economy which also helps

[37] 100% wage stickiness means that wages do not change at all.

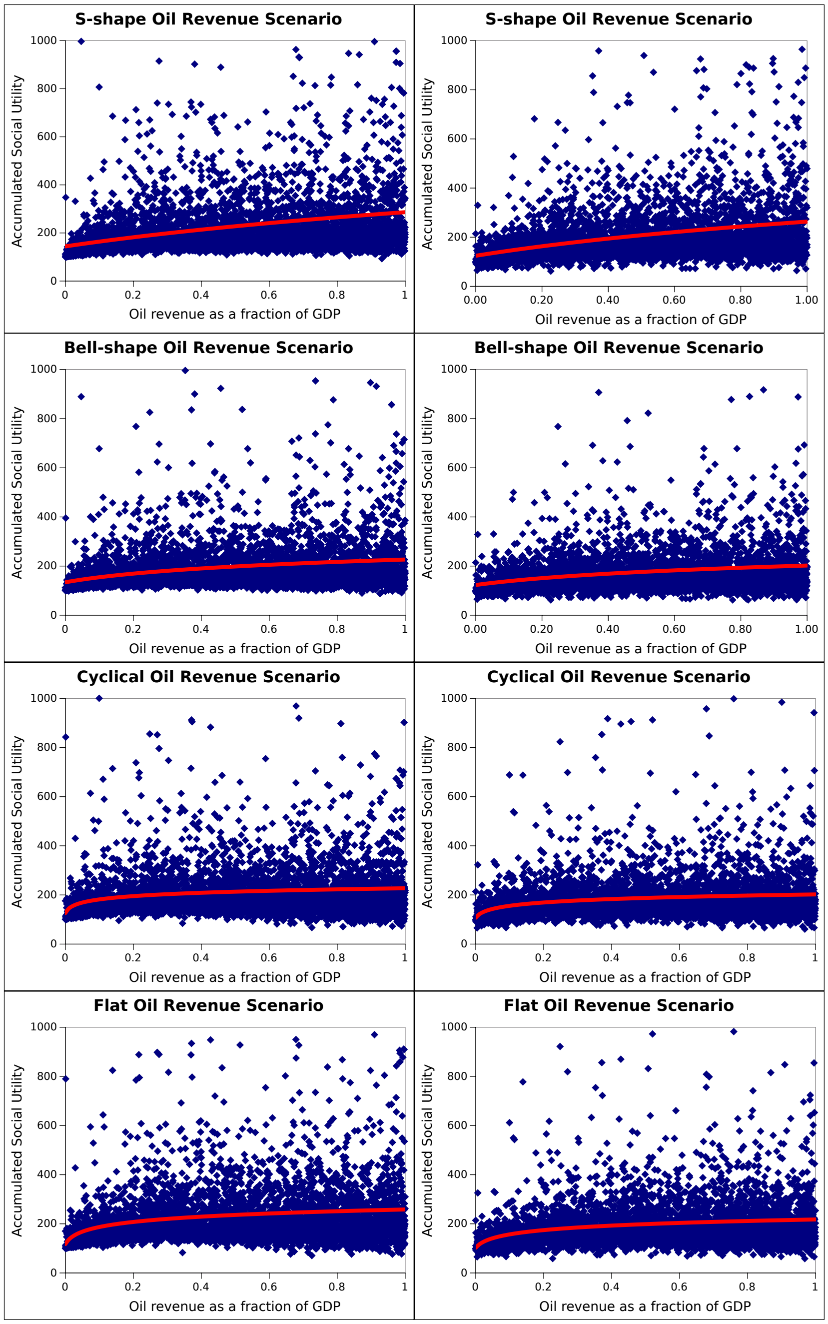

Figure 3.3.4: Relationship between "accumulated social utility" and "average oil revenue" discovered from synthetic data (left column: "normal initial setting"; right column: "low institution" initial setting)

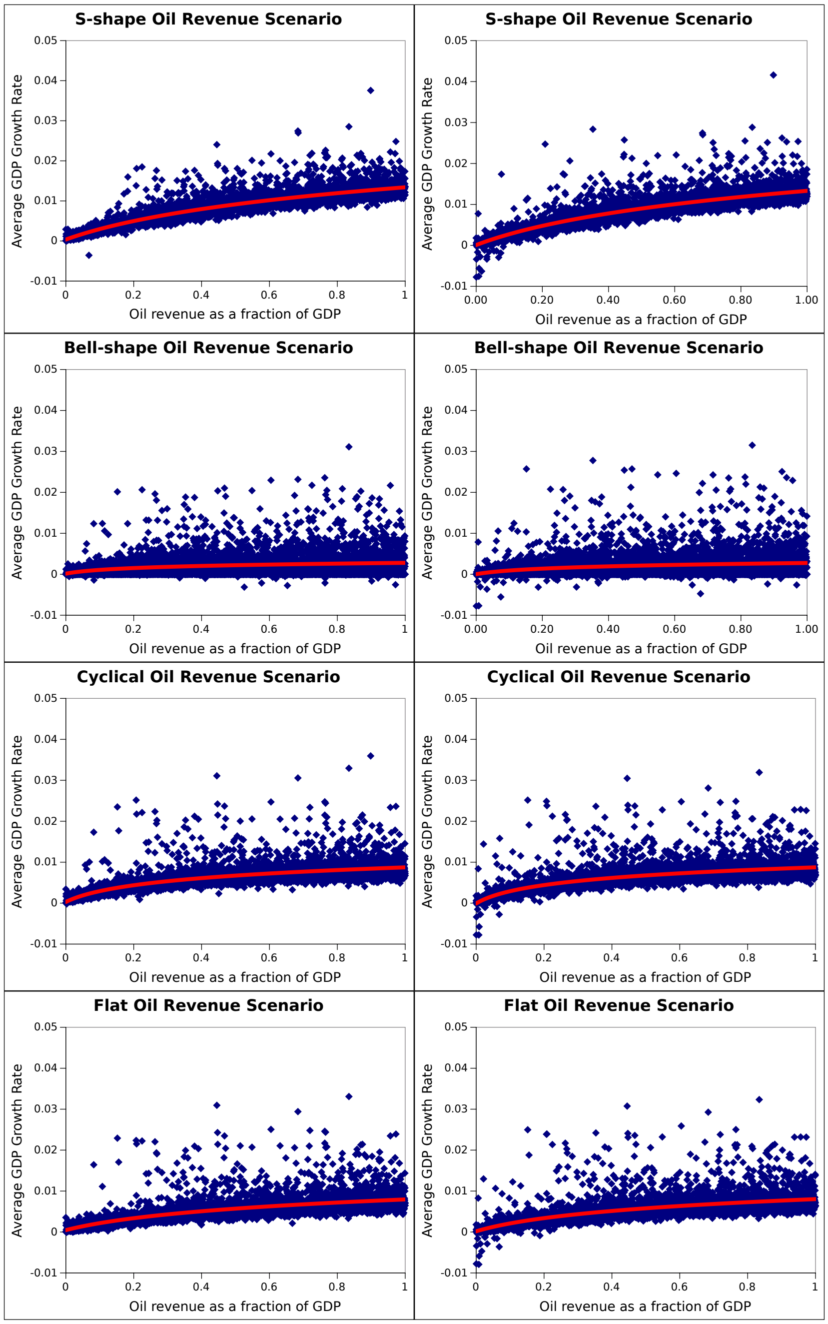

Figure 3.3.5: Relationship between "average GDP growth" and "average oil revenue" discovered from synthetic data (left column: "normal initial setting"; right column: "low institution" initial setting)

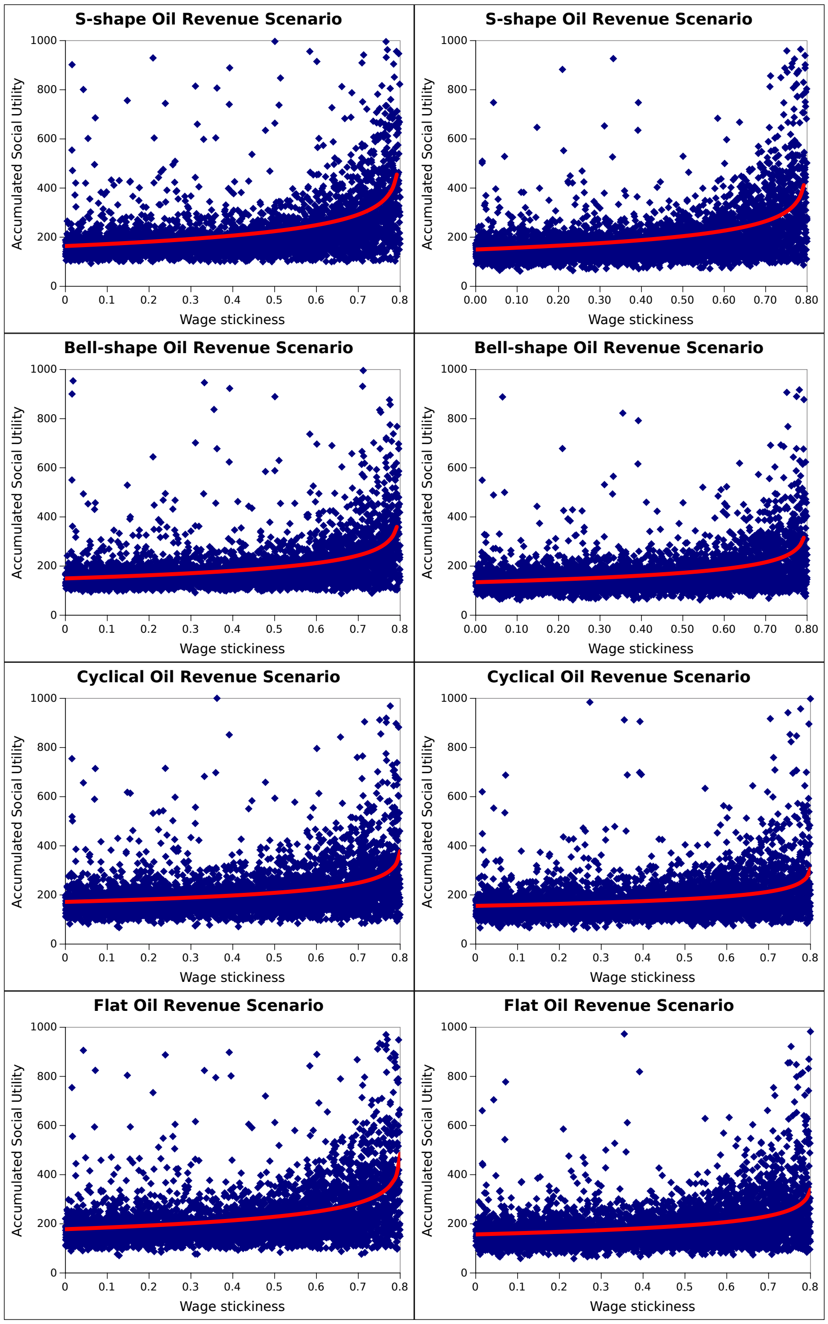

Figure 3.3.6: Relationship between “accumulated social utility” and “wage stickiness” discovered from synthetic data (left column: “normal initial setting”; right column: “low institution” initial setting)

the chaos to decline. Lower corruption and chaos provides a safe environment for the private sector to invest. This helps the economy to flourish and generate even more social utility. A healthy socio-economic development reduces the needs for strict control—because of the low level of chaos. Therefore, the government allocate more resources to economic investment relative to investment in control means. All these improvements help the wage stabilization even further. This ignites a powerful reinforcing feedback loop that helps the society to develop on a healthy trajectory.

Facilitating social mobility

Another leverage point of the system turned out to be the degree to which the society is mobile. Social mobility here is defined as the speed with which citizenry could change their social status. As Fig. 3.3.7 shows, in both initial settings ("normal" and "low institution") the more difficult the social mobility is the lower accumulated social utility would be.

Greater social mobility works simply because it strengthens the negative (balancing) feedback loops discussed in the dynamic hypothesis presented in Section 3.2. Now, productive forces of the society adjust faster to the changes in social settings, thus gaining the advantage of staying in sub-optimal conditions of disequilibrium state for a relatively shorter time period. These results implies that an attempt to facilitate social mobility could improve resource-based development.

Privatization of natural resource revenues

One external policy intervention that could leverage the system is privatization of natural resource revenues. This policy is tested by allocating a fraction (randomly from 0% to 100%) of oil revenue directly to the private sector. Results which are illustrated in Fig. 3.3.8 show that there is an optimal allocation fraction that generates highest level of accumulated social utility. Until a certain threshold, privatization of resource wealth have positive correlation with the accumulated social utility. As the fraction transcends this threshold[38] the social utility tends to decline.

In other words, it will benefit the society if the private sector receives a fraction of natural resource wealth. This wealth strengthens the private sector's economic condition which finally leads to a greater civil society and so on. However, if the allocation fraction exceeds the optimum level—which is indeed unknown—parasites, who are strong in this particular case, would become even stronger through such great source of exploitation. In other words, privatization must happen to strengthen the private sector production but should not be overwhelming to attract parasites.

[38] For our model, this turning point resides around 40% but it can be very different in a real world case. In fact, the numerical value of this fraction is not as important as its existence would be.

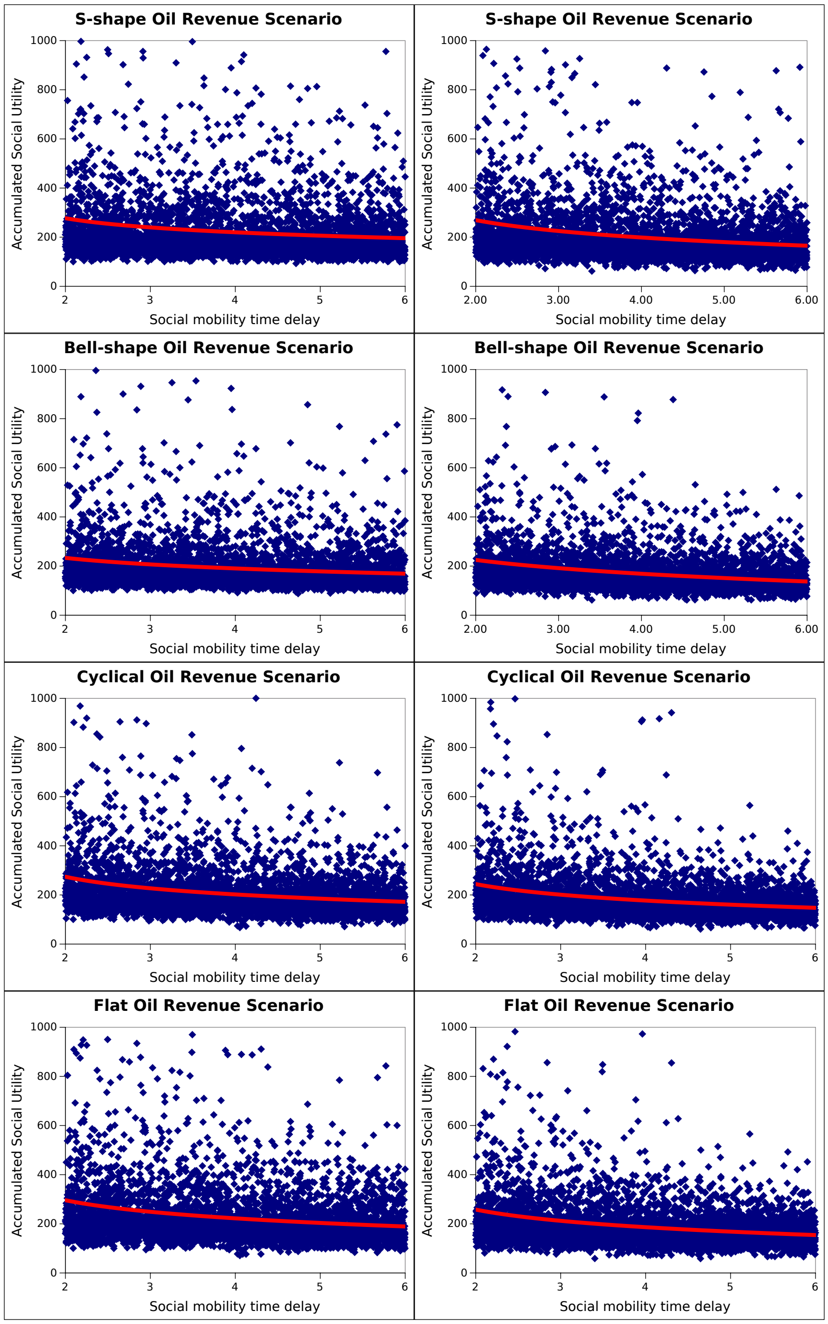

Figure 3.3.7: Relationship between “accumulated social utility” and “social mobility delay time” discovered from synthetic data (left column: “normal initial setting”; right column: “low institution” initial setting)

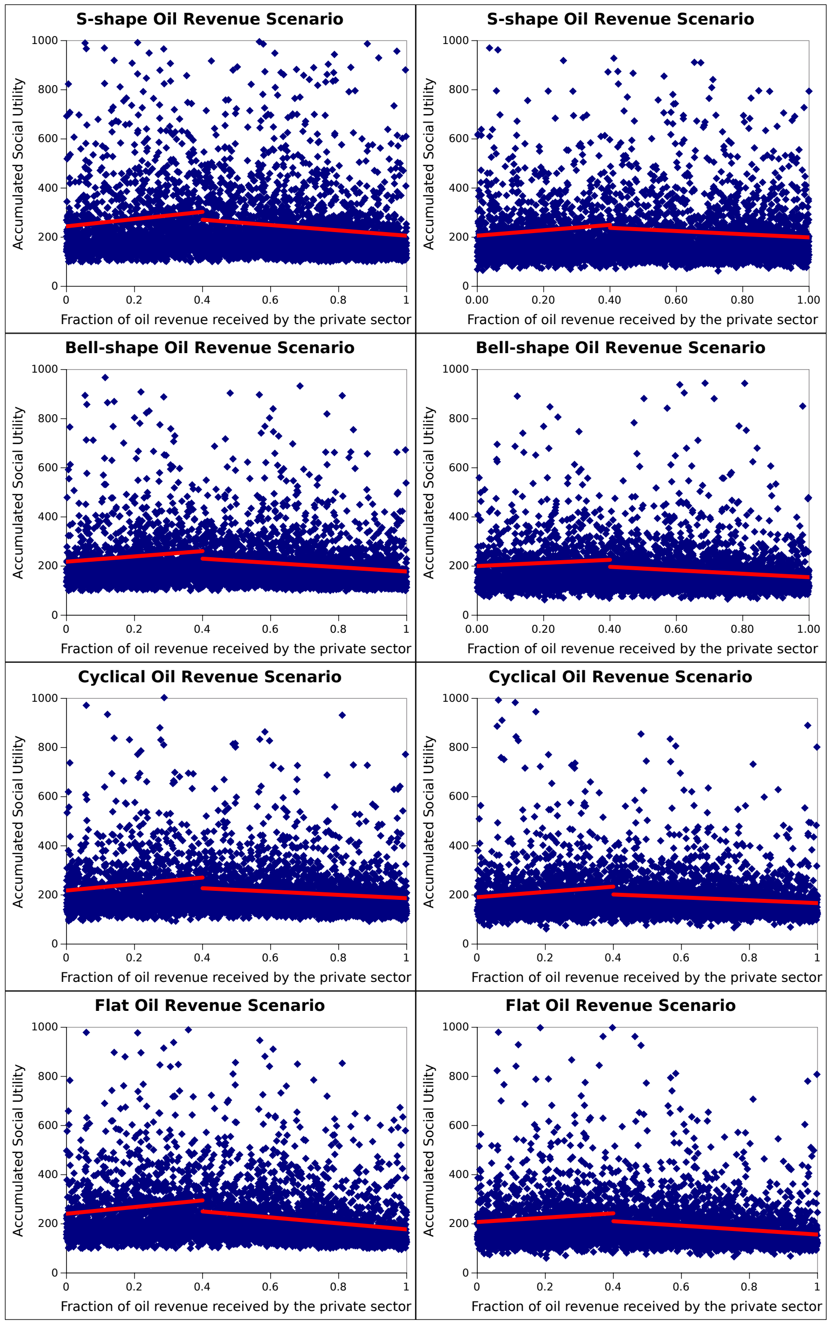

Figure 3.3.8: Relationship between "accumulated social utility" and "privatization of natural resource revenues" discovered from synthetic data (left column: "normal initial setting"; right column: "low institution" initial setting)

Experimentation with the model confirms the findings of recent research on the matter of natural resource curse: there is no definitive answer for the question that whether natural resources are "curse" or "blessing." Either could happen depending on the initial condition of the system. However, our results show that natural resource abundance is more a "blessing" than a "curse."

3.4 Conclusion

In this chapter we developed a generic system dynamics model for the problem of natural resource curse on the basis of well-established theories in this area. The goal has been to decide if natural resource wealth should be considered as "blessing" or "curse" for a particular society. To achieve that goal the concept of "curse" has been revisited and redefined based on modern theories of behavioral economics and psychology. Then a social utility measure has been developed that provides a more comprehensive performance measure for the model. Results show that natural resource curse is unlikely to happen in a controlled environment. This is not because of the new definition of the term "curse." It is shown that even with "economic growth" as a single performance measure, the results will still be robust. In other words, it is very likely that natural resource wealth improves economic growth in the long-run. This is mainly due to the superior methodology that has been deployed in this study. Many factors addressed in the literature are conflicting by nature. For instance, higher growth may lead to worse income equality. When these aspects are studied in isolation results could be misleading, if not wrong.

This study, in contrast, takes a dynamic, feedback-rich, holistic, and long-term approach which enables it to provide a more complete picture of the reality. It also relies on all kinds of available information not only on numerical databases that are largely suspect, especially in developing countries. The model provides an absolutely controllable environment so that pure effect of natural resource wealth could be examined. These characteristics make this study unique and this is perhaps why the results might be different from what the readers may have seen in the past.

Since the model represents a hypothetical social system, there is uncertainty regarding the assumptions and numerical value of the model's parameters. To solve this problem, for every experiment, a multivariate Monte Carlo simulation is conducted with 5,000 runs. In these simulation runs parameters are randomly selected using a uniform distribution function from a wide range of variation [see Appendix B]. Simulation time frame is chosen to be 100 years so that both short-term and long-term effects of natural resource wealth are captured.

Simulation results show that in the long-term "blessing" is a more likely outcome of natural resource wealth than "curse." Having a worse initial social and institutional setting—which is called "low institution" case here—increases likelihood of the "curse" but it does not affect the previous statement. That is, "blessing" is still a more likely outcome of natural resource wealth. In the short-term (less than 10 years), nonetheless, chaos and corruption usually increase.

And, freedom is almost always sacrificed. These results have been robust under many different circumstances. They also show that cyclical natural resource revenue—as a manifestation of unstable stream of revenues—is more likely than other cases of resource revenue (S-shape, bell-shape, and flat) to cause a "curse." In the "low institution" case, however, this is the bell-shape resource revenue—a manifestation of temporary revenue—that is more likely to cause a "curse." Another interesting finding is that natural resource revenue is good for the society but it follows the law of diminishing marginal utility: any additional unit of natural resource revenue increases the social utility but with a decreasing rate.

Experimentation with the model revealed that there are few strategies that could improve the system's behavior. One is stabilization of wage rates. Another is facilitation of social mobility. It is also shown that privatization of natural resource revenues could improve the social utility in a "low institution" case. But there is a threshold for the private sector's direct share of natural resource revenues. Beyond that threshold, privatization may become harmful for the society. Finding that threshold level, thus, could be crucial.

The natural resource curse model we developed in this chapter has gone through a comprehensive series of validation tests. Nevertheless, any model is only a simplified representation of reality and could be subject to errors. There are some limitations that need to be addressed in future research. First, this is a generic model so its behavior does not represent any particular case or country. However, it can replicate different modes of behavior that could be relevant to experiences of some resource-dependent nations. For example, cyclical oil export case could generate an oscillatory behavior which is relevant to experience of countries such as Iran or Iraq. Reducing sensitivity of "state political power" could reproduce a stable behavior mode that is close to experience of countries such as Saudi Arabia. A declining economy could also be replicated by tweaking the model's parameters—e.g. by reducing quality of institutions as well as normal saving and investment rates—which relates to cases such as Nigeria. To achieve a more precise explanation of real world cases we need to classify parameter sets that are responsible for each of them. Considering the long list of parameters, this classification could be an onerous task and deserves a separate study. Any specific and precise policy recommendation for a particular case requires careful calibration of the model for that case. That is beyond the scope of this study.

Second, majority of the model's economic modules are simplified in favor of socio-political aspect of the problem. For instance, money and foreign exchange flows are included in the model but at very aggregate levels. This reduces the model's capability in analyzing monetary policies which require more elaboration. We acknowledge that central banks are very important social institutions and their decisions are intertwined in the "impossible trinity" or "Mundell-Fleming trilemma." Current model needs more elaboration in these area which is open for future research.

Third, many believe that it is hard, if possible at all, to design an aggregate social welfare function (Arrow, 1950; Coleman, 1966). However, considering the magnitude of the problem at hand, it is almost impossible to track utility of individuals. Maybe a hybrid simulation modeling could solve the issue to some degree but it is beyond the scope of this chapter.

Fourth, population growth is assumed to be zero throughout the simulation time. We believe that this does not affect the model's implications but only experimentation could prove us right or wrong. Exclusion of population dynamics also reduces model's capability to account for dynamics of socioeconomic equality. Socioeconomic equality is addressed only at aggregate level in the model. Perhaps a hybrid modeling is required to take further details of population and inequality dynamics into consideration.

Finally, there are also other factors—rather than those seven included in the model—that contribute to social utility. For example, advancement in technology, quality of relationships at individual or community level, religious beliefs, etc. impact social utility (Layard, 2005). It might be interesting to see how natural resource wealth affect these factors. But this is way beyond the current model's boundary.

Appendix A

Initial Value and Variation Range of the Katouzian Model Parameters

Parameter	Description	Min	Base	Max
Capital Formation Delay	Time delay for capital under construction to become complete and ready to use.	3	5	20
Capital Life	Average time that physical capital work before being discarded. This parameter is set to 25 years in Mashayekhi's model of Iranian economic growth.	15	22	30
Capital Output Ratio	The ratio of investment to growth which is equal to 1 divided by the marginal product of capital. The higher the ICOR, the lower the productivity of capital. The ICOR can be thought of as a measure of the inefficiency with which capital is used. In most countries the ICOR is in the neighborhood of 3.	2.5	3.0	3.5

Parameter	Description	Min	Base	Max
Cost per Chaos	Cost per unit of Chaos.	50	100	200
Initial Anger	Initial value of stock of Public Anger	-0.2	0.1	0.2
Initial Chaos	Initial value of stock of Chaos	0.3	0.5	1.0
Initial Corruption	Initial value of stock of Corruption	0.4	0.5	0.6
Initial Power	Initial value of stock of Political Power	0.2	0.5	0.8
Initial Reserve	Initial value of stock of State Reserve	500	1,000	10,000
Initial Respect for Law	Initial value of stock of Respect for Law	0.01	0.05	0.10
Initial Society Capital under Construction	Initial value of stock of Society Capital under Construction	500	2,000	10,000
Initial Society Savings	Initial value of stock of Society Savings	500	2,000	10,000
Initial Society Capital	Initial value of stock of Society Capital	500	2,000	10,000
Initial State Capital under Construction	Initial value of stock of State Capital under Construction	500	2,000	10,000
Initial State Capital	Initial value of stock of State Capital	500	2,000	10,000
Initial Utility	Initial value of stock of Utility	-0.2	0.1	0.2
Investment Fraction	Fraction of stock of savings that will be invested each year	0.1	0.3	0.4
Max Confiscation Fraction	Ultimate fraction of capital that the state can confiscate each year. This level of confiscation will be achievable only when the state is at its maximum political-economic power and when the corruption is at its maximum as well.	0.1	0.3	0.4
Perception Time	Time delay for the society to perceive a phenomenon such as Corruption	3	5	10

Parameter	Description	Min	Base	Max
Regulation Delay	Time delay in decision making at the government level			
Reserve Coverage Time	Benchmark time period during which the government should survive with its current level of revenues and expenditures	10	15	30
Society Memory	Averaging time to smooth historical concepts	3	5	7
Time to Change Chaos	Time delay for Chaos to grow or to be suppressed	3	5	10
Time to Change Power	Time delay for an arbitrary power to consolidate its Political Power or to lose power during a non-violent political transition	3	10	12
Time to Change Respect for Law	Time delay to change the arbitrary culture	20	30	40
Time to Change Utility	Averaging time for smoothing Public Utility	3	5	10
Time to Corrupt	Time delay for Corruption to grow or to decline	3	5	10
Time to Forget	Time delay for a society to forget its good/bad memories	20	30	40
Time to Smooth Probability of Uprising	Time delay for Public Anger to be actively organized and lead to a successful uprising or revolution.	10	15	20

Appendix B

Initial Value and Variation Range of the Resource Curse Model Parameters

Parameter	Description	Min	Base	Max
NCRF	Initial (normal) fraction of government resources allocated to control means	0.1	0.3	0.8
NFTP	Initial (normal) fraction of government financial reserves to be spent on transfer payments	0.01	0.10	0.40
NIF	Initial (normal) investment fraction	0.1	0.3	0.6
NMPC	Initial (normal) marginal propensity to consume	0.6	0.7	0.8
NNTPF	Initial (normal) fraction of production capacity allocated to non-traded goods sector	0.2	0.6	0.8
NTAXR	Initial (normal) tax rate	0.05	0.08	0.16
PCE	Output elasticity of capital	0.3	0.4	0.7
PCEC	Capital elasticity of state control	0.01	0.10	0.50
PCEE	Consumption elasticity of government economic performance	0.1	1.0	2.0
PCH	Natural chaos	0.01	0.02	0.05
PCHIM	Minimum of the function FCHI (effect of chaos on investment C.2.15)	0.01	0.10	0.20
PCHIS	Slope of the function FCHI (effect of chaos on investment C.2.15)	1	2	5
PDSER	Down stickiness of exchange rate	0.0	0.0	0.8
PEA	Concaveness of the function FEA (foreign exchange availability indicator C.6.20)	0.1	0.5	1.0

Parameter	Description	Min	Base	Max
PECC	Parameter to set convexness of the function of exploitability from control (FCFE C.4.13)	1	3	5
PECVR	Parameter to set range of variation for the function of exploitability from control (FCFE C.4.13)	0.2	0.8	1.0
PEEC	Parameter to set concaveness of the function of exploitability from adequacy of economic output (FEFE C.4.18)	0.5	1.0	2.0
PEPC	Concaveness of the function FEPC (effect of state economic performance on fraction of resources allocated to control C.7.47)	1.0	1.2	5.0
PESC	Elasticity of state control	0.1	0.5	0.9
PGRCTM	Minimum of the function FGRCT (effect of government financial reserve coverage time on tax rate C.3.34)	0.65	0.80	0.95
PGRCTS	Slope of the function FGRCT (effect of government financial reserve coverage time on tax rate C.3.34)	1	2	5
PLE	Output elasticity of labor	0.3	0.6	0.7
PMCAF	Maximum fraction of private workforce who are involved in civil activities	0.20	0.25	0.40
PMGIF	Maximum government investment fraction	0.4	0.8	0.9
PMPCS	Slope of the MPC (C.2.24 function	1	2	5
PNTPDS	Down stickiness of non-traded goods price (0 indicates no stickiness; 1 indicates absolute stickiness)	0.0	0.0	0.8
PNTPS	Stickiness of non-traded goods price (0 indicates no stickiness; 1 indicates absolute stickiness)	0.0	0.0	0.8
POILC	Fraction of initial level of total output as constant oil export multiplier	0	0	1
POME	Concaveness of the function FOME (effect of good institutions on exploitability of oil revenues C.4.23)	1	2	4
PPPC	Political performance elasticity of control resource fraction	1	2	5
PPW	Weight of profitability (vs. effect of chaos) in the private investment function (RPI C.2.8)	0.1	0.5	0.9
PQEE	Equality elasticity of government economic performance	0.1	1.0	2.0

Parameter	Description	Min	Base	Max
PRCGE	Concaveness of the function FRCGE (effect of reserve on government employment rate C.1.11)	0.1	2.0	3.0
PRFE	Corruption elasticity of exploitability	1.0	1.5	2.0
PSER	Exchange rate stickiness	0.0	0.0	0.8
PSPE	Elasticity of state political power	0.1	1.0	2.0
PSTPR	Parameter to change variation range of the function FSTP (effect of government popularity on transfer payments C.3.22)	1	2	5
PSTPS	Slope of the function FSTP (effect of government popularity on transfer payments C.3.22)	1.0	1.5	5.0
PTAXRM	Maximum tax rate	0.3	0.4	0.5
PTCA	Convexness of the function FTC (effect of transparency on corruption C.1.23)	1.0	1.5	3.0
PTCC	Convexness of the function FTC (effect of transparency on corruption C.1.23)	0.0	0.5	1.0
PTCM	Concaveness of the function FTCM (Multiplier for adequacy of trade capacity C.6.14)	0.1	4.0	10.0
PTPDS	Down stickiness of traded goods price (0 indicates no stickiness; 1 indicates absolute stickiness)	0.0	0.0	0.8
PTPS	Stickiness of traded goods price (0 indicates no stickiness; 1 indicates absolute stickiness)	0.0	0.0	0.8
PUEE	Unemployment elasticity of government economic performance	0.1	1.0	2.0
PUGIA	A parameter that adjusts minimum of the function FUGI (C.3.7)	0.5	1.0	2.0
PUGIS	Slope of the function FUGI (effect of unemployment rate on government investment C.3.7)	0.5	1.0	2.0
PWA	Concaveness of the workforce availability function	0.1	0.5	2.0
PWCH	Weight of chaos in the social utility function	0	1	5
PWCN	Weight of consumption in the social utility function	0	1	5
PWCO	Weight of corruption in the social utility function	0	1	5
PWDS	Wage down stickiness (0 indicates no stickiness; 1 indicates absolute stickiness)	0.0	0.0	0.8

Parameter	Description	Min	Base	Max
PWEAE	Weight of economic constraints in exploitability function (AE C.4.10)	0.1	0.4	0.5
PWEC	Weight of economy in government resource allocation policy (ACRF C.7.42)	0.1	0.5	0.9
PWEQ	Weight of income equality in the social utility function	0	1	5
PWES	Weight of economy in government popularity function (APS C.7.16)	0.1	0.5	0.9
PWFR	Weight of freedom in the social utility function	0	1	5
PWL	Weight of leisure in the social utility function	0	1	5
PWRAE	Weight of corruption in exploitability function (AE C.4.10)	0.1	0.4	0.5
PWS	Wage stickiness (0 indicates no stickiness; 1 indicates absolute stickiness)	0.0	0.0	0.8
PWUR	Weight of unemployment in the social utility function	0	1	5
TCF	Capital formation time delay	3	6	12
TCL	Capital life	10	15	20
TCRF	Time delay for reallocation of state control resource	2	5	10
TDP	Foreign debt payment time	10	20	30
TEMP	Employment adjustment time delay	2	5	6
TEPP	Time to average economic output that a parasite could exploit	2	5	10
TFREE	Time delay for freedom to be established	1	2	5
TLBD	Time delay to accumulate experience from production	5	10	20
TNID	Time delay for normal imports to decline	1	5	10
TNII	Time delay for normal imports to rise	1	2	10
TP	Perception time delay	2	5	10
TPA	Time delay for prices to adjust	1	5	10
TPCH	Time delay for political power to change	2	5	10
TPM	Length of time people can remember	2	5	10
TPSD	Time delay for government popularity to decrease	1	2	10
TPSI	Time delay for government popularity to increase	1	5	10
TRPF	Time delay to reallocate production factors	1	5	10
TSTF	Time to smooth effect of tax on freedom	1	5	10
TTCA	Time delay to adjust trade capacity	2	5	10
TTPD	Time delay to decrease transfer payments	1	5	10

Parameter	Description	Min	Base	Max
TTPI	Time delay to increase transfer payments	1	2	10
TWA	Time delay for wage rates to adjust	2	5	10

Appendix C

The Resource Curse Model Equations

Since the number of model variables is relatively large a unique naming system is implemented to facilitate readers' comprehension of this long equation list. First character in a variable name shows its type. There are 6 variable types in the model: levels, rates, auxiliaries, functions, (constant) parameters, and time (constants). Levels are variables that accumulate over time. Name of a level starts with L, e.g. LU represents stock of unemployed workforce. Initial values of levels start with the letter N. Rate variables directly change the value of levels. Name of such variables starts with an R. Auxiliary variables conserve computations that are usually used in rate variable. These start with the letter A. Functions are a special type of auxiliaries that contain more complex formulas. Initial character of such variables' name is F. Parameters are constant values that are used in computation of other variables. Name of parameters start with the letter P. And finally, time constants are a particular type of parameters that represent time delays in the model. Their initial is T.

Please note that some level variables have equations for their initial values instead of constant numerics. This is to automatically calculate appropriate values for the initial state of the model so that it always starts in equilibrium, no matter how constant parameters of the model are set.

In general, equation references follow this format:

First line: equation

Second line: description [unit of measure]

Next line: name and description of variable(s) / parameter(s) that are used in the equation (cross-reference for variable(s) / parameter(s)) [unit of measure].

Please also note that the Dollar sign ($) in the paper does not represent US Dollar but is merely used as a generic unit of domestic currency.

C.1 Employment

There are two major production factors in the model: labor and capital. This module is responsible for allocation of labor to different production sectors including private and government sectors. Three main employment states in the model are: "private workforce," "government workforce," and "unemployed" workforce. Some theories attribute the natural resource curse to the development of corruption and rent-seeking behavior which leads to sub-optimal policies regarding the extraction and export of natural resources (Auty, 2001; Isham et al., 2005). To capture dynamics of corruption and rent-seeking behavior two additional employment states are included: "corrupt officers"—a fraction of government workforce which is engaged in corrupt activities—and parasites—a fraction of workforce population which is engaged in all sorts of illegal and/or harmful (for the society as a whole) activities including rent-seeking behavior[1]. To control corruption and rent-seeking behavior societies must strengthen their civil institutions that are the most effective system of checks and balances (Acemoglu et al., 2003; Acemoglu and Robinson, 2005; Mehlum et al., 2006). The sixth and final employment state of the model is "civil activists" as representative of the civil society. More precisely, civil activists are defined here to be a fraction of workforce population which is involved in non-profit activities in order to improve citizen's social life and to correct social injustice. This part of the population is responsible for development of "good institutions" which are considered to be the foundation of a steady socio-political-economic development (Acemoglu and Robinson, 2012).

There is not sharp contrast between different employment states in the real world. If we think of these employment states as fractions of time an individual spends on those particular social roles, then the deployed division makes sense. For example, a government employee might do his/her job reasonably well and within the boundaries of law but accepts bribes once in a while—say, 1% of the time. A government with 100 of such employees could be represented in our model with 99 persons in the state of "government workforce" and 1 person in the state of "corrupt officers." Same logic applies to the other states[2]. Few of us—if any—might work full-time as a civil activist. A fraction of our time, nonetheless, may be spent on things that contribute to development of the civil society. Therefore, the model has "person" as a unit of measure for the employment states but total population sums up to 100 in all situations so that it could be easy to interpret each employment state as a percentage of total workforce population.

LU is a stock of unemployed workforce that could be employed by either private sector or government.

[1]Saeed et al. (2013) call this division of population as "bandits." "Bandits" do not have a normal job but earn income by participating in illegal, criminal, or corrupt activities.

[2]Another way to look at this division is to consider the content of each employment state as FTEs (full-time equivalents).

$$LU_t = LU_0 - \int_0^t (RPWA_\tau + RGWA_\tau + RUP_\tau) \cdot d\tau \tag{C.1.1}$$

$$LU_0 = (NCW + NCO + NGW + NPW + NPAR) \cdot \frac{PNUR}{(1 - PNUR)}$$

LU	=	unemployed workforce [Person]
NCW (C.1.32)	=	Initial (normal) population of civil activists [Person]
NCO (C.1.18)	=	Initial (normal) population of corrupt officers [Person]
NGW (C.1.16)	=	Initial (normal) population of workforce employed in the government sector [Person]
NPW (C.1.41)	=	Initial (normal) population of workforce employed in the private sector [Person]
NPAR (C.1.43)	=	Initial (normal) population of parasites: part of workforce who do not work but enjoy consuming others' production [Person]
PNUR (C.1.49)	=	Natural unemployment rate [Person]
RPWA (C.1.3)	=	Workforce adjustment rate in the private sector [Person/ Year]
RGWA (C.1.2)	=	Workforce adjustment rate in the government sector [Person/ Year]
RUP (C.1.47)	=	Number of unemployed workforce who become parasite every year [Person/ Year]

Please note that initial unemployed workforce (LU_0) is a function of other parameters. It is so because we want to make sure that unemployment rate is always equal to natural unemployment rate ($PNUR$) at initial condition, independent of the value of other parameters or initial states. This ensures that the model always starts in equilibrium.

State of unemployed workforce can change mainly by private and/or government hiring (firing) activities. Here, this is called "workforce adjustment." Workforce adjustment could be positive or negative. When positive, workforce are becoming employed. When negative, workforce are becoming unemployed. Eq. C.1.2 represents government workforce adjustment rate. It simply tries to reduce the gap between current and desired states of government workforce. Same mechanism applies to the private sector workforce adjustment (see Eq. C.1.3). It is assumed that workforce adjustment takes about 5 years to reach a full balance due to intrinsic delays in the labor market.

$$RGWA_t = \frac{\min(AGWG_t, LU_t)}{3 \cdot TEMP} \tag{C.1.2}$$

RGWA	=	Workforce adjustment rate in the government sector [Person/ Year]
AGWG (C.1.5)	=	Workforce gap in the government sector [Person]
LU (C.1.1)	=	Unemployed workforce [Person]
TEMP (C.1.4)	=	Employment adjustment time delay [Year]

$$RPWA_t = \frac{\min(APWG_t, LU_t)}{3 \cdot TEMP} \tag{C.1.3}$$

RPWA	=	Workforce adjustment rate in the private sector [Person/ Year]
APWG (C.1.6)	=	Workforce gap in the private sector [Person]
LU (C.1.1)	=	Unemployed workforce [Person]
TEMP (C.1.4)	=	Employment adjustment time delay [Year]

$$TEMP = 5 \tag{C.1.4}$$

TEMP	=	Employment adjustment time delay [Year]

$$AGWG_t = AGDW_t - LGW_t \tag{C.1.5}$$

AGWG	=	Workforce gap in the government sector [Person]
AGDW (C.1.7)	=	Government desired workforce [Person]
LGW (C.1.15)	=	Workforce employed in the government sector [Person]

$$APWG_t = APDW_t - LPW_t \tag{C.1.6}$$

APWG	=	Workforce gap in the private sector [Person]
APDW (C.1.13)	=	Private sector desired workforce [Person]
LPW C.1.40	=	Workforce employed in the private sector [Person]

Government workforce contributes to both production and control. As we will see later, relative significance of this contribution is endogenously determined depending on several factors. So, government desired workforce is a sum of desired workforce for control and for economic investments. This sum will also be limited by the government financial constraints.

$$AGDW_t = (AGDWC_t + AGDWI_t) \cdot FRCGE_t \tag{C.1.7}$$

AGDW	=	Government desired workforce [Person]
AGDWC (C.1.10)	=	Government desired workforce for the purpose of control [Person]
AGDWI (C.1.8)	=	Government desired workforce for investment [Person]
FRCGE (C.1.11)	=	Effect of government financial reserve coverage on the government employment rate [Dimensionless]

Desired workforce from investment is proportionate to the investment rate. This proportion is determined by the parameter shown in Eq. C.1.9. This is a parametric solution that ensures initial value of desired workforce is equal to the current workforce so that the model will start in equilibrium state.

$$AGDWI_t = RGI_t \cdot NGDWI \tag{C.1.8}$$

AGDWI	=	Government desired workforce for investment [Person]
RGI (C.3.6)	=	Government sector investment rate [$/ Year]
NGDWI (C.1.9)	=	Government sector desired workforce per unit of investment in the sector [Person-Year/ $]

$$NGDWI = \frac{(1 - NCRF) \cdot NGW}{RGI_0} \tag{C.1.9}$$

NGDWI	=	Government sector desired workforce per unit of investment in the sector [Year-Person/ $]
NCRF (C.7.36)	=	Initial (normal) fraction of government resources allocated to control means [Dimensionless]
NGW (C.1.16)	=	Initial (normal) government sector workforce [Person]
RGI (C.3.6)	=	Government sector investment rate [$/ Year]

Government also needs workforce for the purpose of control. This requirement depends on the level of sociopolitical chaos[3]. Higher levels of chaos makes the government to require more enforcement power and thus more workforce will be needed.

$$AGDWC_t = NCRF \cdot NGW \cdot \frac{LPCH_t}{LPCH_0} \tag{C.1.10}$$

[3]The concept of "chaos" will be discussed later in Section C.7.

AGDWC	=	Government desired workforce for the purpose of control [Person]
NCRF (C.7.36)	=	Initial (normal) fraction of government resources allocated to control means [Dimensionless]
NGW (C.1.16)	=	Initial (normal) government sector workforce [Person]
LPCH (C.7.8)	=	Perceived chaos [Dimensionless]

Finally, the government financial state affects its employment rate. This effect is represented by Eq. C.1.11.

$$FRCGE_t = \frac{2/\left(1 + e^{-\frac{PRCGE \cdot AGRC_t}{AGRC_0}}\right) - 1}{2/\left(1 + e^{-PRCGE}\right) - 1} \tag{C.1.11}$$

FRCGE	=	Effect of government financial reserve coverage on the government employment rate [Dimensionless]
PRCGE (C.1.12)	=	Concaveness of the function FRCGE: effect of reserve on government employment rate [Dimensionless]
AGRC (C.3.39)	=	Government financial reserve coverage time [Year]

$$PRCGE = 2 \tag{C.1.12}$$

PRCGE	=	Concaveness of the function FRCGE (effect of reserve on government employment rate—C.1.11) [Dimensionless]

Different governments may have different human resource policies with varying sensitivity to their financial limitations. Some may be very conservative and thus limit employment of new workforce in face of a financial difficulty. Others might be more liberal in this regard. Parameter $PRCGE$ in Eq. C.1.11 determines this level of cautiousness. Variation in the output of this equation in response to different values of $PRCGE$ is depicted in Fig. C.1.1. Higher values of $PRCGS$ represent more liberal policy mindset in relation to government expenditure. Lower values of $PRCGS$ represent a more frugal governance. This is particularly important for testing hypotheses that state liberal public spending in the face of a natural resource windfall could lead to a curse. Government expenditures will be discussed in further details in Section C.3.

Private sector's desired workforce, in contrast to the government's, depends only on investment rate in the sector.

$$APDW_t = NPDWI \cdot RPI_t \tag{C.1.13}$$

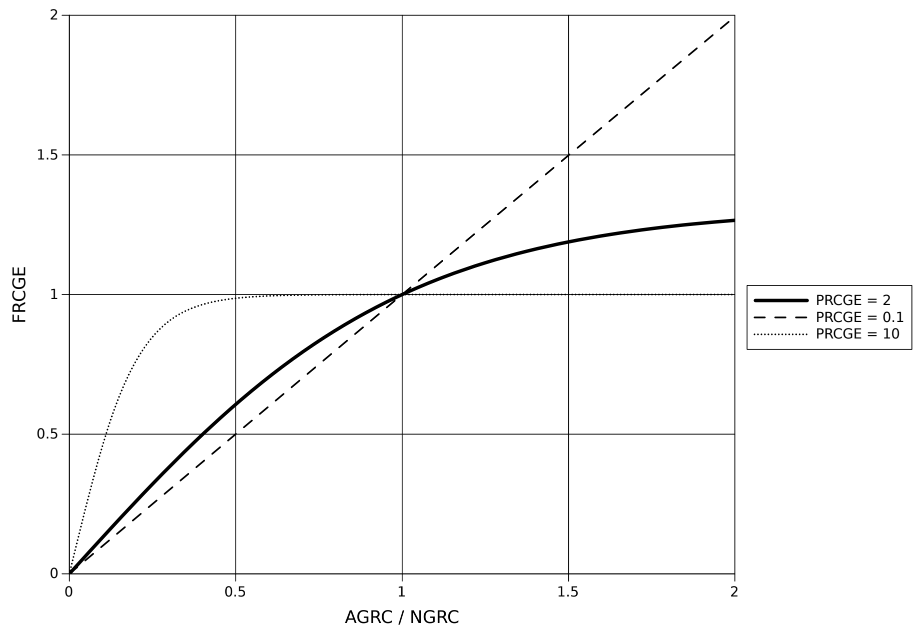

Figure C.1.1: Effect of government's financial state on its desired workforce

APDW	=	Private sector desired workforce [Person]
NPDWI (C.1.14)	=	Private sector desired workforce per unit of investment in the sector [Year*Person/ $]
RPI (C.2.8)	=	Private sector investment rate [$/ Year]

$$NPDWI = \frac{NPW}{RPI_0} \tag{C.1.14}$$

NPDWI	=	Private sector desired workforce per unit of investment in the sector [Year*Person/ $]
NPW (C.1.41)	=	Initial (normal) private sector workforce [Person]
RPI (C.2.8)	=	Private sector investment rate [$/ Year]

Government workforce adjustment modifies the level of government workforce. This level is also affected by corruption rate ($RGCO$ C.1.19).

$$LGW_t = LGW_0 + \int_0^t (RGWA_\tau - RGCO_\tau) \cdot d\tau \tag{C.1.15}$$
$$LGW_0 = NGW$$

LGW	=	Workforce employed in the government sector [Person]
NGW (C.1.16)	=	Initial (normal) government sector workforce [Person]
RGWA (C.1.2)	=	Workforce adjustment rate in the government sector [Person/ Year]
RGCO (C.1.19)	=	Government workforce who become corrupt [Person/ Year]

$$NGW = 30 \tag{C.1.16}$$

NGW = Initial (normal) government sector workforce [Person][4]

$RGCO$ can be positive or negative. As corruption increases $RGCO$ becomes positive and stock of government workforce depletes and adds up to the stock of "corrupt offices" (LCO C.1.17). Negative values of $RGCO$ works in reverse direction.

$$LCO_t = LCO_0 + \int_0^t RGCO_\tau \cdot d\tau \tag{C.1.17}$$
$$LCO_0 = NCO$$

LCO	=	Corrupt government officers: part of the government workforce who get involved in corrupt and illegal activities [Person]
NCO (C.1.18)	=	Initial (normal) corrupt government officers [Person]
RGCO (C.1.19)	=	Government workforce who become corrupt [Person/ Year]

$$NCO = 5 \tag{C.1.18}$$

NCO = Initial (normal) corrupt government officers [Person]

$$RGCO_t = \frac{\max(0, AICO_t - LCO_t) \cdot FGWA_t + \min(0, AICO_t - LCO_t)}{TEMP} \tag{C.1.19}$$

[4]Population of employment states and their corresponding parameters are scaled down in order to reduce unnecessary numerical complexity.

RGCO	=	Government workforce who become corrupt [Person/Year]
AICO (C.1.22)	=	Indicated corrupt government officers [Person]
LCO (C.1.17)	=	Corrupt government officers: part of the government workforce who get involved in corrupt and illegal activities [Person]
FGWA (C.1.20)	=	Availability indicator of the government sector workforce [Dimensionless]
TEMP (C.1.4)	=	Employment adjustment time delay [Year]

The function FGWA (C.1.20) provides a first order control so that the population of government workforce (*LGW*—C.1.15) will never go below zero.

$$FGWA_t = \frac{(PWA + 1) \cdot LGW_t/NGW}{PWA + LGW_t/NGW} \tag{C.1.20}$$

FGWA	=	Availability indicator of the government sector workforce [Dimensionless]
PWA (C.1.21)	=	Concaveness of the workforce availability function [Dimensionless]
LGW (C.1.15)	=	Workforce employed in the government sector [Person]
NGW (C.1.16)	=	Initial (normal) population of workforce employed in the government sector [Person]

$$PWA = 0.5 \tag{C.1.21}$$

PWA	=	Concaveness of the workforce availability function [Dimensionless]

Concept of corruption in developing countries has been widely studied[5]. Here, we define corruption as an aggregate measure of all sorts of illegal activities practiced by government officials that could lead to distortion of normal distribution of scarce resources. Corruption rate in the model depends on two factors: attractiveness of corrupt activities and transparency. Attractiveness of corruption is assumed to be equal to attractiveness of illegal activities—something that is called being "parasite" here. An incentive for being a parasite generates incentives for government officials to get involve in some sorts of illegal activities or corruption. For instance, if there is a considerable stake in drug trafficking then dealers may be willing to offer notable bribes to border patrol agents. These incentives may be significant in some cases and insignificant in others. Nonetheless, it should be reasonable to assume that their average value

[5]See Søreide (2014) for a comprehensive overview.

is proportionate to "parasite attractiveness." Attractiveness of being parasite will be discussed later.

$$AICO_t = NCO \cdot AAP_t \cdot FTC_t \tag{C.1.22}$$

AICO	=	Indicated corrupt government officers [Person]
NCO (C.1.18)	=	Initial (normal) corrupt government officers [Person]
AAP (C.4.43)	=	Attractiveness of being parasite [Dimensionless]
FTC (C.1.23)	=	Effect of good institutions on corruption [Dimensionless]

Although not decisive, but transparency is another key factor affecting the rate of corruption (Kolstad and Wiig, 2009). A transparent society is less susceptible to corruption. Some scholars believe that a broader set of factors aggregated in the concept of "good institutions" are responsible for the magnitude of corruption (Mehlum et al., 2006; Robinson et al., 2014). Good institutions are those social settings which foster socio-political-economic growth while bad institutions encourage rent-seeking and other harmful social behavior. Impact of good institution on corruption is represented by Eq. C.1.23:

$$FTC_t = \frac{2/\left(1 + e^{\dfrac{PTCA \cdot LGI_t}{LGI_0}}\right) + PTCC}{2/\left(1 + e^{PTCA}\right) + PTCC} \tag{C.1.23}$$

FTC	=	Effect of good institutions on corruption [Dimensionless]
PTCA (C.1.24)	=	Convexness of the function FTC: effect of good institutions on corruption [Dimensionless]
LGI (C.1.26)	=	Number of good institutions [Dimensionless]
PTCC (C.1.25)	=	Slope of the function FTC: effect of good institutions on corruption [Dimensionless]

$$PTCA = 1.5 \tag{C.1.24}$$

PTCA	=	Convexness of the function FTC (effect of good institutions on corruption C.1.23)

$$PTCC = 0.5 \tag{C.1.25}$$

PTCC = Slope of the function FTC: effect of good institutions on corruption [Dimensionless]

This function creates a relationship between the magnitude of good institutions and level of corruption. $PTCA$ and $PTCC$ are parameters that help us to test different levels of sensitivity of corruption to good institutions. As illustrated in Fig. C.1.2, variation in these parameters alters the shape of the function.

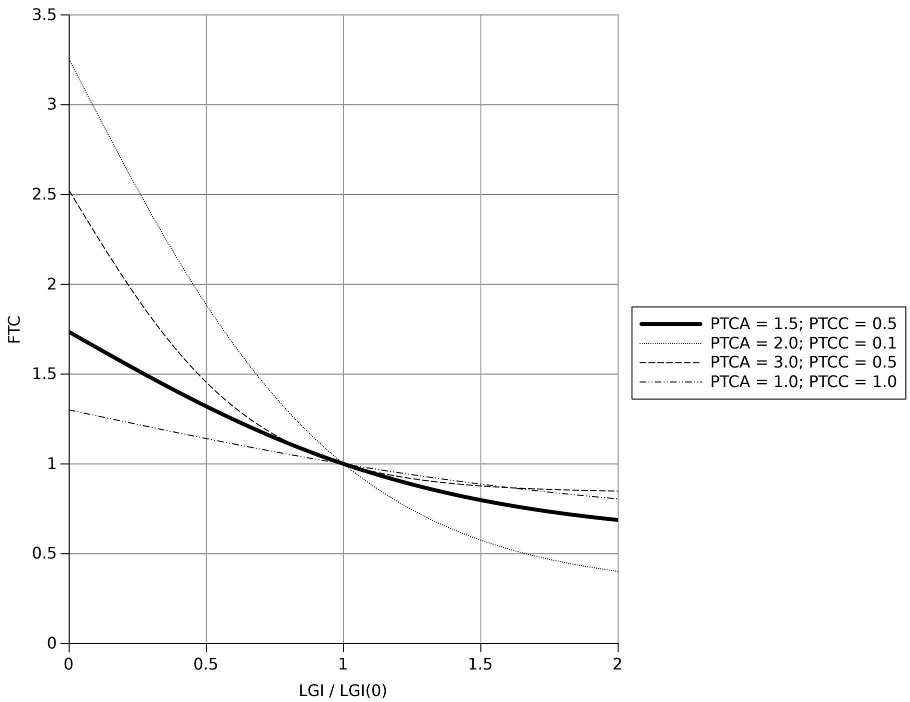

Figure C.1.2: Effect of good institutions on corruption

Magnificence of good institutions, on the other hand, is determined by the level of civil right activities. Good institutions are developed and maintained by the civil society. Benevolent dictatorship could also help to develop good institutions but those institutions may not last for long if the civil society has not developed to maturity (Langarudi and Radzicki, 2015). One may argue that this also depends on other factors such as state control too. As we will see later, such factors come into play to affect growth of the civil society, thus they eventually affect the institutions in one way or another.

$$LGI_t = LGI_0 + \int_0^t (RII_\tau - RID_\tau) \cdot d\tau \qquad \text{(C.1.26)}$$

$$LGI_0 = RII_0 \cdot TIL$$

LGI	=	Number of good institutions
RII (C.1.27)	=	Institution development rate [1/Year]
RID (C.1.29)	=	Institution decay [1/Year]
TIL (C.1.30)	=	Institution life time [Year]

Development of good institution not only depends on activities of the civil society but is also affected by activists' relative economic power. As the civil society tries to establish its power, those who benefit from corruption and chaos act in the opposite direction trying to counter establishment of good institutions which will be a limiting factor for their economic advantages.

$$RII_t = NID_t \cdot \frac{LCW_t \cdot LWR_t}{APARI_t} \qquad \text{(C.1.27)}$$

RII	=	Institution development rate [1/Year]
NID (C.1.28)	=	Initial (normal) institution development rate [1/Year]
LCW (C.1.31)	=	Workforce employed by civil institutions [Person]
LWR (C.5.4)	=	Average wage rate of the working class [$/ Year-Person]
APARI (C.4.5)	=	Total income of parasites [$/Year]

$$NID = 20 \qquad \text{(C.1.28)}$$

NID	=	Initial (normal) institution development rate [1/Year]

$$RID_t = \frac{LGI_t}{TIL} \qquad \text{(C.1.29)}$$

RID	=	Institution decay [1/Year]
LGI (C.1.26)	=	Number of good institutions
TIL (C.1.30)	=	Institution life time [Year]

$$TIL = 5 \qquad \text{(C.1.30)}$$

TIL = Institution life time [Year]

Population of civil activists is a fraction of private sector workforce. This fraction could change depending on two factors: level of freedom in the society, and economic welfare of the working class.

$$LCW_t = LCW_0 + \int_0^t RPCA_\tau \cdot d\tau \tag{C.1.31}$$
$$LCW_0 = NCW$$

LCW	=	Workforce employed by civil institutions [Person]
NCW (C.1.32)	=	Initial (normal) civil activist population [Person]
RPCA (C.1.35)	=	Private sector workforce who become civil activist [Person/ Year]

$$NCW = NCAF \cdot NPW \tag{C.1.32}$$

NCW	=	Initial (normal) civil activist population [Person]
NCAF (C.1.33)	=	Initial (normal) fraction of private workforce who are involved in civil activities [Dimensionless]
NPW (C.1.41)	=	Initial (normal) private sector workforce [Person]

$$NCAF = 0.1 \tag{C.1.33}$$

NCAF = Initial (normal) fraction of private workforce who are involved in civil activities [Dimensionless]

$$APOP_t = LCW_t + LCO_t + LGW_t + LPW_t + LP_t + LU_t \tag{C.1.34}$$

APOP	=	Workforce population [Person]
LCW (C.1.31)	=	Workforce employed by civil institutions [Person]
LCO (C.1.17)	=	Corrupt government officers: part of the government workforce who get involved in corrupt and illegal activities [Person]
LGW (C.1.15)	=	Workforce employed in the government sector [Person]
LPW C.1.40	=	Workforce employed in the private sector [Person]
LP (C.1.42)	=	Parasites: part of workforce who do not work but enjoy consuming of others' production [Person]
LU (C.1.1)	=	Unemployed workforce [Person]

$$RPCA_t = \frac{AICA_t - LCW_t}{TEMP} \qquad \text{(C.1.35)}$$

RPCA	=	Private sector workforce who become civil activist [Person/ Year]
AICA (C.1.36)	=	Indicated civil activist population [Person]
LCW (C.1.31)	=	Workforce employed by civil institutions [Person]
TEMP (C.1.4)	=	Employment adjustment time delay [Year]

$$AICA_t = NCAF \cdot LPW_t \cdot FFCAG_t \cdot FWCAG_t \qquad \text{(C.1.36)}$$

AICA	=	Indicated civil activist population [Person]
NCAF (C.1.33)	=	Initial (normal) fraction of private workforce who are involved in civil activities [Dimensionless]
LPW (C.1.40)	=	Workforce employed in the private sector [Person]
FFCAG (C.1.37)	=	Effect of freedom on growth of civil activist population [Dimensionless]
FWCAG (C.1.39)	=	Effect of economic welfare on growth of civil activist population [Dimensionless]

Freedom is an indicator for coercion of the state. High levels of freedom show relatively high tolerance of the government towards the society and its activism (see Eq. C.7.28). A coercive government limits the space for civil activism. One may argue that lack of freedom may also encourage civil activism. That might be true if we limit the definition of civil activism to be relevant only to political matters. Nevertheless, the term "civil activism" here refers to a broader concept that encompasses other areas such as environmental, cultural, economic, and social issues. In fact, it is assumed that in presence of a coercive government "civil activism" in total becomes less significant. However, distribution of forces within the body of activist may align towards political issues. Therefore, one possible relationship between freedom and civil activism could be defined as follows:

$$FFCAG_t = \frac{2/\left(1 + e^{-LFREE_t \cdot \ln \frac{1+NCAF/PMCAF}{1-NCAF/PMCAF}}\right) - 1}{2/\left(1 + e^{-\ln \frac{1+NCAF/PMCAF}{1-NCAF/PMCAF}}\right) - 1} \qquad \text{(C.1.37)}$$

FFCAG	=	Effect of freedom on growth of civil activist population [Dimensionless]
LFREE (C.7.28)	=	Freedom [Dimensionless]
NCAF (C.1.33)	=	Initial (normal) fraction of private workforce who are involved in civil activities [Dimensionless]
PMCAF (C.1.38)	=	Maximum fraction of private workforce who are involved in civil activities [Dimensionless]

$$PMCAF = 0.25 \tag{C.1.38}$$

PMCAF = Maximum fraction of private workforce who are involved in civil activities [Dimensionless]

Shape of this function and its variations in response to changes in parameters $NCAF$ and $PMCAF$ are shown in Fig. C.1.3.

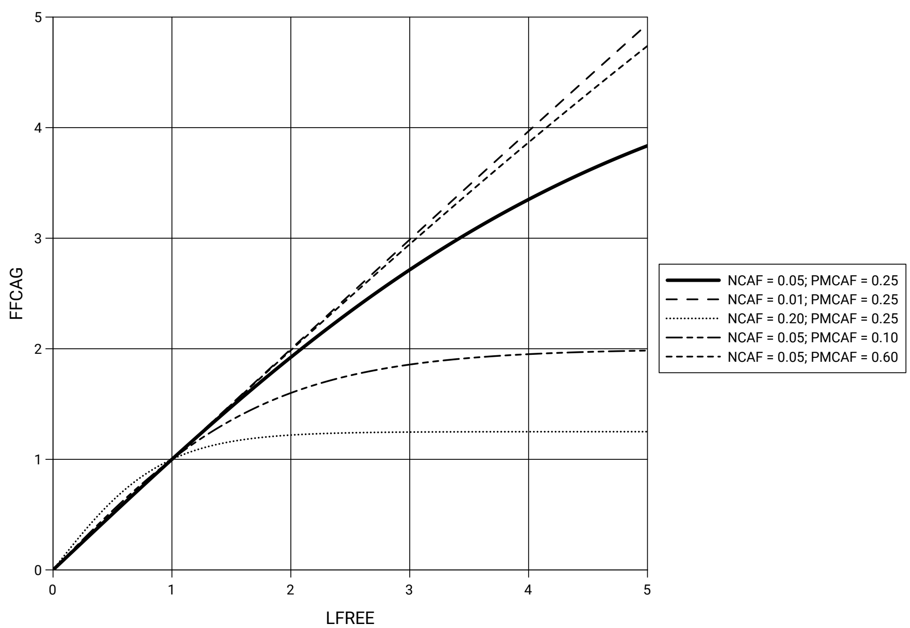

Figure C.1.3: Effect of freedom on civil activism

Economic condition of the middle class—represented here by the average wage rate of workers—directly affects the level of civil activities (Oliver, 1999). Eq. C.1.39 shows such impact. Shape of this function and its variation are exactly similar to those of Eq. C.1.37 (see Fig. C.1.3).

$$FWCAG_t = \frac{2/\left(1+e^{-\frac{LWR_t}{NWR}\cdot\ln\frac{1+NCAF/PMCAF}{1-NCAF/PMCAF}}\right)-1}{2/\left(1+e^{-\ln\frac{1+NCAF/PMCAF}{1-NCAF/PMCAF}}\right)-1} \tag{C.1.39}$$

FWCAG	=	Effect of economic welfare on growth of civil activist population [Dimensionless]
LWR (C.5.4)	=	Average wage rate of the working class [$/ Year-Person]
NWR (C.5.2)	=	Initial (normal) average wage rate of the working class [$/ Year-Person]
NCAF (C.1.33)	=	Initial (normal) fraction of private workforce who are involved in civil activities [Dimensionless]
PMCAF (C.1.38)	=	Maximum fraction of private workforce who are involved in civil activities [Dimensionless]

As people spend more of their time on civil activities they will have less time to spend on productive work. Population of private workforce (shown in Eq. C.1.40) represent total human resources the private sector allocates to production of goods and services.

$$LPW_t = LPW_0 + \int_0^t (RPWA_\tau - RPCA_\tau - RPPAR_\tau)\cdot d\tau \tag{C.1.40}$$
$$LPW_0 = NPW$$

LPW	=	Workforce employed in the private sector [Person]
NPW (C.1.41)	=	Initial (normal) private sector workforce [Person]
RPWA (C.1.3)	=	Workforce adjustment rate in the private sector [Person/ Year]
RPCA (C.1.35)	=	Private sector workforce who become civil activist [Person/ Year]
RPPAR (C.1.44)	=	Private workforce who become parasite [Person/ Year]

$$NPW = 50 \tag{C.1.41}$$

NPW	=	Initial (normal) private sector workforce [Person]

Parts of private workforce may become parasites depending on how attractive it is to become a parasite [6].

$$LP_t = LP_0 + \int_0^t (RPPAR_\tau + RUP_\tau) \cdot d\tau \quad \text{(C.1.42)}$$
$$LP_0 = NPAR$$

LP	=	Parasites: part of workforce who do not work but enjoy consuming of others' production [Person]
NPAR (C.1.43)	=	Initial (normal) parasites [Person]
RPPAR (C.1.44)	=	Private workforce who become parasite [Person]
RUP (C.1.47)	=	Unemployed workforce who become parasite [Person]

$$NPAR = 5 \quad \text{(C.1.43)}$$

NPAR	=	Initial (normal) parasites [Person]

$$RPPAR_t = \max(0, AIPAR_t - LP_t) \cdot \frac{FPWA_t}{TEMP} \quad \text{(C.1.44)}$$

RPPAR	=	Private workforce who become parasite [Person/ Year]
AIPAR (C.1.45)	=	Indicated population of parasites [Person]
LP (C.1.42)	=	Parasites: part of workforce who do not work but enjoy consuming of others' production [Person]
FPWA (C.1.46)	=	Availability indicator of the private sector workforce [Dimensionless]
TEMP (C.1.4)	=	Employment adjustment time delay [Year]

$$AIPAR_t = NPAR \cdot AAP_t \quad \text{(C.1.45)}$$

[6] We define the variable "parasites" as a fraction of private human resources that is allocated to extraction and consumption of the society's resources without contributing to its production. Please note that all the stocks (levels) in the model are average of the corresponding variable. For example, an individual could be at the same time in stock of LPW (C.1.40) and LP (C.1.42). In other words, individuals could spend some part of their life being productive but also in some other parts of their lives they can get involve in illegal activities, or any engagement that might be harmful for the rest of the society—this is called being a "parasite" here. Another way to think of this concept is to consider each of the levels as an accumulation of FTEs (Full Time Equivalents) the society allocates to different activities. While these FTEs could be separable at the aggregate level, they may be distributed differently for individuals. Since the model here deals only with aggregate variables at the societal level, this separation of FTEs is a reasonable assumption.

AIPAR	=	Indicated population of parasites [Person]
NPAR (C.1.43)	=	Initial (normal) population of parasites: part of workforce who do not work but enjoy consuming others' production [Person]
AAP (C.4.43)	=	Attractiveness of being parasite [Dimensionless]

$$FPWA_t = \frac{(PWA+1) \cdot LPW_t/NPW}{PWA + LPW_t/NPW} \tag{C.1.46}$$

FPWA	=	Availability indicator of the private sector workforce [Dimensionless]
PWA (C.1.21)	=	Concaveness of the workforce availability function [Dimensionless]
LPW (C.1.40)	=	Workforce employed in the private sector [Person]
NPW (C.1.41)	=	Initial (normal) population of workforce employed in the private sector [Person]

Unemployed workforce have more incentives than the employed people to become parasites:

$$RUP_t = \frac{\min(AIPAR_t - LP_t, LU_t)}{3 \cdot TEMP} \tag{C.1.47}$$

RUP	=	Unemployed workforce who become parasite [Person/Year]
AUR (C.1.48)	=	Unemployment rate [Dimensionless]
PNUR (C.1.49)	=	Natural unemployment rate [Person]
AIPAR (C.1.45)	=	Indicated population of parasites [Person]
LP (C.1.42)	=	Parasites: part of workforce who do not work but enjoy consuming of others' production [Person]
TEMP (C.1.4)	=	Employment adjustment time delay [Year]

$$AUR_t = \frac{LU_t}{APOP_t} \tag{C.1.48}$$

AUR	=	Unemployment rate [Dimensionless]
LU (C.1.1)	=	Unemployed workforce [Person]
APOP (C.1.34)	=	Workforce population [Person]

$$PNUR = 0.05 \tag{C.1.49}$$

PNUR	=	Natural unemployment rate (Dimensionless)

C.2 Private Investment

This section describes the process of capital formation in the private sector. This process is relatively straightforward and mainly based upon conventional theories of economic growth.

Capital formation rate ($RPCF$) accumulates in the stock of capital (LPC) and depreciation ($RPCD$) drains it:

$$LPC_t = LPC_0 + \int_0^t (RPCF_\tau - RPCD_\tau) \cdot d\tau \qquad \text{(C.2.1)}$$
$$LPC_0 = NPC$$

LPC	=	Stock of private capital [$]
NPC (C.2.2)	=	Initial (normal) private capital [$]
RPCF (C.2.5)	=	Private capital formation rate [$/Year]
RPCD (C.2.4)	=	Private capital depreciation rate [$/Year]

$$NPC = RPCF_0 \cdot TCL \qquad \text{(C.2.2)}$$

NPC	=	Initial (normal) private capital [$]
RPCF (C.2.5)	=	Private capital formation rate [$/Year]
TCL (C.2.3)	=	Capital life [Year]

$$TCL = 15 \qquad \text{(C.2.3)}$$

TCL = Capital life [Year]

$$RPCD_t = LPC_t/TCL \qquad \text{(C.2.4)}$$

RPCD	=	Private capital depreciation rate [$/Year]
LPC (C.2.1)	=	Stock of private capital [$]
TCL (C.2.3)	=	Capital life [Year]

Capital in progress ($LPCP$) flows into the stock of capital (LPC) with a delay (TCF). This flow is affected by availability of workforce in the sector ($FPWA$):

$$RPCF_t = \frac{LPCP_t \cdot FPWA_t}{TCF} \tag{C.2.5}$$

RPCF	=	Private capital formation rate [$/Year]
LPCP (C.2.7)	=	Private capital in progress [$]
FPWA (C.1.46)	=	Availability indicator of the private sector workforce [Dimensionless]
TCF (C.2.6)	=	Capital formation time delay [Year]

$$TCF = 6 \tag{C.2.6}$$

TCF	=	Capital formation time delay [Year]

$LPCP$ increases as the the private sector invests from its financial reserves:

$$LPCP = \int_0^t (RPI_\tau - RPCF_\tau) \cdot d\tau \tag{C.2.7}$$
$$LPCP_0 = RPI_0 \cdot TCF$$

LPCP	=	Private capital in progress [$]
RPI (C.2.8)	=	Private sector investment rate [$/Year]
RPCF (C.2.5)	=	Private capital formation rate [$/Year]
TCF (C.2.6)	=	Capital formation time delay [Year]

Besides availability of financial reserves, investment in the private sector depends on two factors: profitability of production in the sector and level of chaos in the society.

$$RPI_t = LPR_t \cdot NIF \cdot LPP_t^{PPW} \cdot FCHI_t^{1-PPW} \tag{C.2.8}$$

RPI	=	Private sector investment rate [$/Year]
LPR (C.2.19)	=	Private sector financial reserves [$]
NIF (C.2.9)	=	Initial (normal) investment fraction [1/Year]
LPP (C.2.11)	=	Perceived profitability [Dimensionless]
PPW (C.2.10)	=	Weight of profitability (vs effect of chaos) in the private investment function [Dimensionless]
FCHI (C.2.15)	=	Effect of chaos on investment [Dimensionless]

$$NIF = 0.2 \tag{C.2.9}$$

NIF = Initial (normal) investment fraction [1/Year]

$$PPW = 0.5 \tag{C.2.10}$$

PPW = Weight of "profitability" (relative to "effect of chaos") in the private investment function [Dimensionless]

It takes some time for investors to fully perceive profitability of production in the sector[7].

$$LPP_t = LPP_0 + \int_0^t \left(\frac{FP_\tau - LPP_\tau}{TP}\right) \cdot d\tau \tag{C.2.11}$$
$$LPP_0 = 1$$

LPP	=	Perceived profitability [Dimensionless]
FP (C.2.13)	=	Profitability of the private production [Dimensionless]
TP (C.2.12)	=	Perception time delay [Year]

$$TP = 5 \tag{C.2.12}$$

TP = Perception time delay [Year]

$$FP_t = \begin{cases} \dfrac{2/\left(1 + e^{\frac{-PPC \cdot NPC \cdot APP_t}{APP_0 \cdot LPC_t}}\right) - 1}{2/\left(1 + e^{-PPC}\right) - 1} & , APP_t > 0 \\ 0 & , APP_t \leq 0 \end{cases} \tag{C.2.13}$$

[7]Please note that a max function is used to take only positive values of profits into account. In fact, it is assumed that the private sectors shuts down its investment as long as profits are negative.

FP	=	Profitability of the private production [Dimensionless]
PPC (C.2.14)	=	Concaveness of the profitability function [Dimensionless]
NPC (C.2.2)	=	Initial (normal) private capital [$]
APP (C.4.25)	=	Private profit [$/Year]
LPC (C.2.1)	=	Stock of private capital [$]

$$PPC = \ln\left(\frac{1+NIF}{1-NIF}\right) \tag{C.2.14}$$

PPC	=	Concaveness of the profitability function [Dimensionless]
NIF (C.2.9)	=	Initial (normal) investment fraction [1/Year]

The profitability function (FP) which determines the effect of profitability on private investment can take different shapes depending on the value of normal investment fraction (NIF). These variations are shown in Fig. C.2.1.

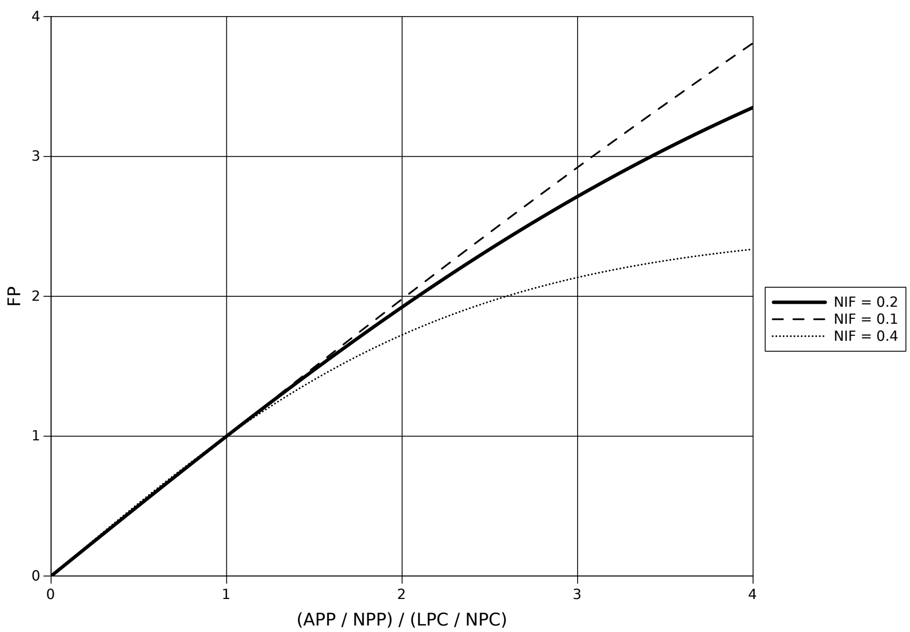

Figure C.2.1: Effect of profitability on private investment

Another factor affecting the investment rate is sociopolitical chaos. Here the term "chaos" is defined as unlawful behavior of citizens in all levels of a society. This includes, theft, violence, arbitrary government actions, tax evasion, or any other kind of action that breaks the rule of law. From this point of view, chaos—which conceptually is very close to lawlessness—has a negative impact on private investment (Dixit, 2007; Haggard and Tiede, 2011). Eq. C.2.15 which is graphically illustrated in Fig. C.2.2 replicates this negative relationship.

$$FCHI_t = PCHIM + \frac{(1 - PCHIM) * (1 + NCHIM)}{NCHIM + (LPCH_t/LPCH_0)^{PCHIS}} \tag{C.2.15}$$

FCHI	=	Effect of chaos on investment [Dimensionless]
PCHIM (C.2.16)	=	Minimum of the function FCHI (effect of chaos on investment) [Dimensionless]
NCHIM (C.2.17)	=	Maximum of the function FCHI: effect of chaos on investment [Dimensionless]
LPCH (C.7.8)	=	Perceived chaos [Dimensionless]
PCHIS (C.2.18)	=	Slope of the function FCHI: effect of chaos on investment [Dimensionless]

$$PCHIM = 0.1 \tag{C.2.16}$$

PCHIM	=	Minimum of the function FCHI (effect of chaos on investment) [Dimensionless]

$$NCHIM = \frac{(PCHIM - 1) \cdot NIF}{NIF - 1} \tag{C.2.17}$$

PCHIM	=	Maximum of the function FCHI (effect of chaos on investment) [Dimensionless]

$$PCHIS = 2 \tag{C.2.18}$$

PCHIS	=	Slope of the function FCHI (effect of chaos on investment) [Dimensionless]

While investment rate depletes private sector's financial reserves, saving rate increases them:

$$LPR_t = LPR_0 + \int_0^t (RPS_\tau - RPI_\tau) \cdot d\tau \tag{C.2.19}$$

$$LPR_0 = NDI \cdot \frac{1 - NMPC}{NIF}$$

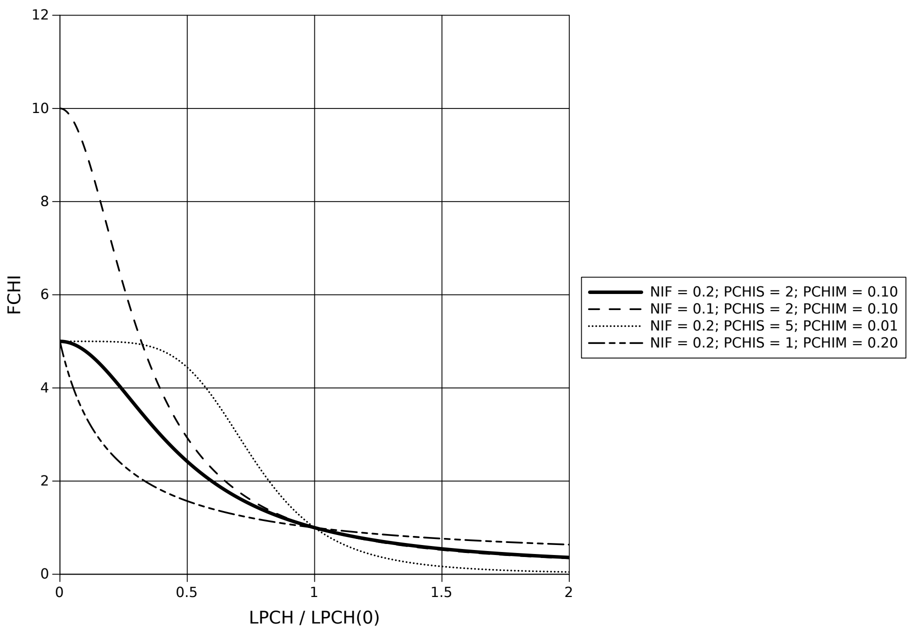

Figure C.2.2: Effect of chaos on private investment

LPR	=	Private sector financial reserves [$]
RPS (C.2.21)	=	Saving rate of the private sector [$/Year]
RPI (C.2.8)	=	Private sector investment rate [$/Year]
NDI (C.2.27)	=	Initial (normal) disposable income [$/Year]
NMPC (C.2.20)	=	Initial (normal) marginal propensity to consume [Dimensionless]
NIF (C.2.9)	=	Initial (normal) investment fraction [1/Year]

$$NMPC = 0.7 \tag{C.2.20}$$

NMPC	=	Initial (normal) marginal propensity to consume [Dimensionless]

$$RPS_t = ADI_t - APCt \tag{C.2.21}$$

RPS	=	Saving rate of the private sector [$/Year]
ADI (C.2.22)	=	Disposable income [$/Year]
APC (C.2.23)	=	Private consumption [$/Year]

From national accounting we have:

$$ADI_t = AO_t - ATAX_t + LATP_t - AGO_t + AGW_t \tag{C.2.22}$$

ADI	=	Disposable income [$/Year]
AO (C.4.26)	=	Total output of the economy [$/Year]
ATAX (C.3.31)	=	Government tax revenues [$/Year]
LATP (C.3.15)	=	Average transfer payments [$/Year]
AGO (C.4.27)	=	Total economic output of the government [$/Year]
AGW (C.4.3)	=	Wages paid by the government [$/Year]

A fraction of income will be consumed every year. Note that the consumption function is non-linear. In fact, MPC (marginal propensity to consume) is a function of disposable income. For higher levels of disposable income, MPC is lower and vice versa.

$$APC_t = ADI_t \cdot FMPC_t \tag{C.2.23}$$

APC	=	Private consumption [$/Year]
ADI (C.2.22)	=	Disposable income [$/Year]
FMPC (C.2.24)	=	Marginal propensity to consume [Dimensionless]

$$FMPC_t = PMPCM + \frac{1 - PMPCM}{(ADI_t/NDI)^{PMPCS} + 1} \tag{C.2.24}$$

FMPC	=	Marginal propensity to consume [Dimensionless]
PMPCM (C.2.25)	=	Minimum marginal propensity to consume [Dimensionless]
ADI (C.2.22)	=	Disposable income [$/Year]
NDI (C.2.27)	=	Initial (normal) disposable income [$/Year]
PMPCS (C.2.26)	=	Slope of the MPC function [Dimensionless]

$$PMPCM = 2 \cdot NMPC - 1 \tag{C.2.25}$$

PMPCM	=	Minimum marginal propensity to consume [Dimensionless]
NMPC (C.2.20)	=	Initial (normal) marginal propensity to consume [Dimensionless]

$$PMPCS = 4 \tag{C.2.26}$$

PMPCS = Slope of the MPC function [Dimensionless]

For the base case, normal MPC is set to 0.7 but other values could also be tested for this function. Furthermore, slope of the MPC function could change. Fig. C.2.3 shows variation of this function in response to different values of $PMPCS$.

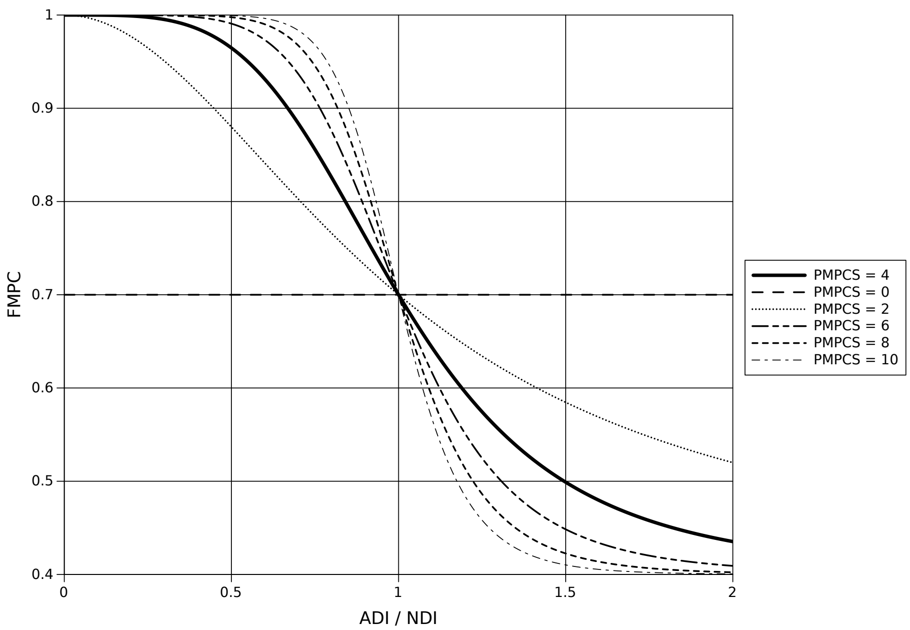

Figure C.2.3: Marginal propensity to consume

$$\begin{aligned} NDI = {} & NO - NTAXR \cdot (NO - NWR \cdot (NCO + NPAR)) \\ & + LGR_0 \cdot NFTP + NWR \cdot (NGW + NCO) - NGO \end{aligned} \tag{C.2.27}$$

NDI	=	Initial (normal) disposable income [$/Year]
NO (C.4.19)	=	Initial (normal) total output of the economy [$/Year]
NTAXR (C.3.33)	=	Initial (normal) tax rate [Dimensionless]
NWR (C.5.2)	=	Initial (normal) average wage rate of the working class [$/Year-Person]
NCO (C.1.18)	=	Initial (normal) corrupt government officers [Person]
NPAR (C.1.43)	=	Initial (normal) parasites [Person]
LGR (C.3.13)	=	Government financial reserves [$]
NFTP (C.3.21)	=	Initial (normal) fraction of government financial reserves to be spent on transfer payments [1/Year]
NGW (C.1.16)	=	Initial (normal) population of workforce employed in the government sector [Person]
NGO (C.4.35)	=	Initial (normal) government production [$/Year]

C.3 Government Investment

Government investment module has a capital chain similar to the private investment module (see Section C.2). Only new features are explained in this section.

$$LGC_t = LGC_0 + \int_0^t (RGCF_\tau - RGCD_\tau) \cdot d\tau \qquad \text{(C.3.1)}$$
$$LGC_0 = NGC$$

LGC	=	Stock of government capital [$]
NGC (C.3.2)	=	Initial (normal) government capital [$]
RGCF (C.3.4)	=	Government capital formation rate [$/Year]
RGCD (C.2.4)	=	Government capital depreciation rate [$/Year]

$$NGC = RGCF_0 \cdot TCL \qquad \text{(C.3.2)}$$

NGC	=	Initial (normal) government capital [$]
RGCF (C.3.4)	=	Government capital formation rate [$/Year]
TCL (C.2.3)	=	Capital life [Year]

$$RGCD_t = LGC_t / TCL \qquad \text{(C.3.3)}$$

RGCD	=	Government capital depreciation rate [$/Year]
LGC (C.3.1)	=	Stock of government capital [$]
TCL (C.2.3)	=	Capital life [Year]

$$RGCF_t = \frac{LGCP_t \cdot FGWA_t}{TCF} \tag{C.3.4}$$

RGCF	=	Government capital formation rate [$/Year]
LGCP (C.3.5)	=	Government capital in progress [$]
FGWA (C.1.20)	=	Availability indicator of the government sector workforce [Dimensionless]
TCF (C.2.6)	=	Capital formation time delay [Year]

$$LGCP = \int_0^t (RGI_\tau - RGCF_\tau) \cdot d\tau \tag{C.3.5}$$
$$LGCP_0 = RGI_0 \cdot TCF$$

LGCP	=	Government capital in progress [$]
RGI (C.3.6)	=	Government sector investment rate [$/Year]
RGCF (C.3.4)	=	Government capital formation rate [$/Year]
TCF (C.2.6)	=	Capital formation time delay [Year]

Unlike the private sector's, government investment is not driven by profitability. Instead, it is driven by public needs and availability of public funds. Unemployment rate is used as a proxy to signal the government that the economy needs state intervention so public expenditures could be adjusted accordingly. As unemployment rises the government increases its investment in order to compensate for shortage of private investment. If unemployment rate declines, government expenditure will be used differently.

$$RGI_t = LGR_t \cdot NIF \cdot FUGI_t \tag{C.3.6}$$

RGI	=	Government sector investment rate [$/Year]
LGR (C.3.13)	=	Government financial reserves [$]
NIF (C.2.9)	=	Initial (normal) investment fraction [1/Year]
FUGI (C.3.7)	=	Effect of unemployment on the government investment rate [Dimensionless]

$$FUGI_t = \left(2/\left(1 + e^{-PUGIA \cdot \left(\left(\frac{LPUR_t}{PNUR}\right)^{PUGIS} - 1\right)}\right)\right)^{PUGIR} \tag{C.3.7}$$

FUGI	=	Effect of unemployment on the government investment rate [Dimensionless]
PUGIA (C.3.8)	=	A parameter that adjusts minimum of the function $FUGI$; the greater the $PUGIA$ the lower the mininum of $FUGI$ [Dimensionless]
LPUR (C.3.9)	=	Perceived unemployment rate [Dimensionless]
PNUR (C.1.49)	=	Natural unemployment rate [Dimensionless]
PUGIS (C.3.10)	=	Slope of the function $FUGI$ (effect of unemployment rate on government investment) [Dimensionless]
PUGIR (C.3.11)	=	Variation range of the function $FUGI$ (effect of unemployment rate on government investment) [Dimensionless]

$$PUGIA = 1 \tag{C.3.8}$$

PUGIA	=	A parameter that adjusts minimum of the function $FUGI$; the greater the $PUGIA$ the lower the mininum of $FUGI$ [Dimensionless]

$$LPUR_t = LPUR_0 + \int_0^t \frac{AUR_\tau - LPUR\tau}{TP} \cdot d\tau \tag{C.3.9}$$
$$LPUR_0 = PNUR$$

LPUR	=	Perceived unemployment rate [Dimensionless]
PNUR (C.1.49)	=	Natural unemployment rate [Dimensionless]
AUR (C.1.48)	=	Unemployment rate [Dimensionless]
TP (C.2.12)	=	Perception time delay [Year]

$$PUGIS = 2 \tag{C.3.10}$$

PUGIS	=	Slope of the function $FUGI$ (effect of unemployment rate on government investment) [Dimensionless]

$$PUGIR = \ln\left(\frac{PMGIF/NIF}{\ln 2}\right) \tag{C.3.11}$$

PUGIR	=	Variation range of the function *FUGI* (effect of unemployment rate on government investment) [Dimensionless]
PMGIF (C.3.12)	=	Maximum government investment fraction [1/Year]
NIF (C.2.9)	=	Initial (normal) investment fraction [1/Year]

$$PMGIF = 0.8 \tag{C.3.12}$$

PMGIF = Maximum government investment fraction [1/Year]

FUGI function (Eq. C.3.7) provides a wide range of alternative state policies for the case of government investment in response to the state of unemployment. Fig. C.3.1 shows some of these alternatives. For example, the government with the parameter set ($PUGIS = 1.0, PUGIA = 0.5$) is relatively slow in reacting to changes in unemployment while the government with the parameter set ($PUGIS = 3.0, PUGIA = 0.1$) reacts slowly only when unemployment rate declines below normal rate. It acts rather aggressively when unemployment rises above normal rate.

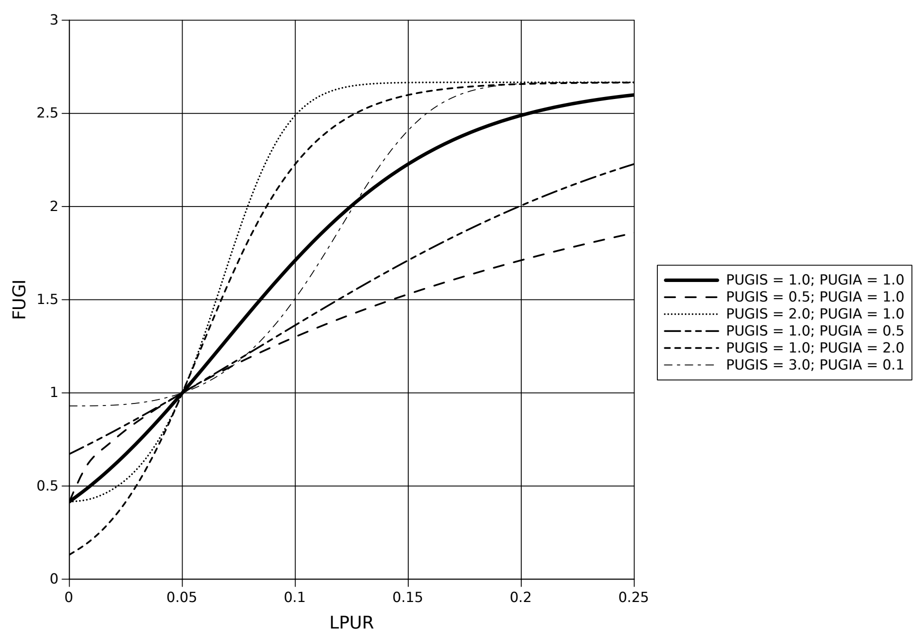

Figure C.3.1: Effect of unemployment on government investment

Government financial reserves is a stock that accumulates government revenues. Government expenditure and investment deplete this stock.

$$LGR_t = LGR_0 + \int_0^t (RGR_\tau + RM - RGE_\tau - RGI_\tau) \cdot d\tau \tag{C.3.13}$$

$$LGR_0 = (NTAXR \cdot (NO - NWR \cdot (NCO + NPAR)) - (NGW + NCO) \cdot NWR + NGO)/(NFTP + NIF)$$

LGR	=	Government financial reserves [$]
RGR (C.3.30)	=	Government revenues [$/Year]
RM (C.3.43)	=	Rate of issuing new money [$/Year]
RGE (C.3.14)	=	Government expenditure [$/Year]
RGI (C.3.6)	=	Government sector investment rate [$/Year]
NTAXR (C.3.33)	=	Initial (normal) tax rate [Dimensionless]
NO (C.4.19)	=	Initial (normal) total output of the economy [$/Year]
NWR (C.5.2)	=	Initial (normal) average wage rate of the working class [$/Year-Person]
NCO (C.1.18)	=	Initial (normal) corrupt government officers [Person]
NPAR (C.1.43)	=	Initial (normal) parasites [Person]
NGW (C.1.16)	=	Initial (normal) population of workforce employed in the government sector [Person]
NGO (C.4.35)	=	Initial (normal) government production [$/Year]
NFTP (C.3.21)	=	Initial (normal) fraction of government financial reserves to be spent on transfer payments [1/Year]
NIF (C.2.9)	=	Initial (normal) investment fraction [1/Year]

Government expenditure includes wage and transfer payments:

$$RGE_t = LATP_t + AGW_t \tag{C.3.14}$$

RGE	=	Government expenditure [$/Year]
LATP (C.3.15)	=	Average transfer payments [$/Year]
AGW (C.4.3)	=	Wages paid by the government [$/Year]

Wage payments will be discussed in Section C.5. Here, we focus on transfer payments, though. It is assumed that governments—particularly in developing countries—increase transfer payments in case of a natural resource windfall. However, they do not react symmetrically when the opposite happens i.e. when government revenues decline for whatever reason (Karl, 1997, 1999). It is because citizens become used to a certain level of consumption and any reduction in that level of consumption could cause a significant surge in public dissatisfaction. Such decline in public satisfaction may not be very desirable for any government. But it can be fatal particularly for democratic governments. Therefore, it is assumed that the level of transfer payments changes asymmetrically:

it grows faster than it declines. This assumption is applied by selecting different time delays for increase and decrease of transfer payments. Transfer payments decrease more slowly than than they increase.

$$LATP_t = LATP_0 + \int_0^t (RTPI_\tau - RTPD_\tau) \cdot d\tau \qquad \text{(C.3.15)}$$

$$LATP_0 = NFTP \cdot (NTAXR \cdot (NO - NWR \cdot (NCO + NPAR)) - (NGW + NCO) \cdot NWR + NGO)/(NFTP + NIF)$$

LATP	=	Average transfer payments [$/Year]
RTPI (C.3.16)	=	Rate of increase of transfer payments [$/$Year^2$]
RTPD (C.3.17)	=	Rate of decline of transfer payments [$/$Year^2$]
NFTP (C.3.21)	=	Initial (normal) fraction of government financial reserves to be spent on transfer payments [1/Year]
NTAXR (C.3.33)	=	Initial (normal) tax rate [Dimensionless]
NO (C.4.19)	=	Initial (normal) total output of the economy [$/Year]
NWR (C.5.2)	=	Initial (normal) average wage rate of the working class [$/Year-Person]
NCO (C.1.18)	=	Initial (normal) corrupt government officers [Person]
NPAR (C.1.43)	=	Initial (normal) parasites [Person]
NGW (C.1.16)	=	Initial (normal) population of workforce employed in the government sector [Person]
NGO (C.4.35)	=	Initial (normal) government production [$/Year]
NIF (C.2.9)	=	Initial (normal) investment fraction [1/Year]

$$RTPI_t = \frac{\max(0, ADTP_t - LATP_t)}{TTPI} \qquad \text{(C.3.16)}$$

RTPI	=	Rate of increase of transfer payments [$/$Year^2$]
ADTP (C.3.20)	=	Desired transfer payments [$/Year]
LATP (C.3.15)	=	Average transfer payments [$/Year]
TTPI (C.3.18)	=	Time delay to increase transfer payments [Year]

$$RTPD_t = -\frac{\min(0, ADTP_t - LATP_t)}{TTPD} \qquad \text{(C.3.17)}$$

RTPD	=	Rate of decline of transfer payments [$/$Year^2$]
ADTP (C.3.20)	=	Desired transfer payments [$/Year]
TTPD (C.3.19)	=	Time delay to decrease transfer payments [Year]

$$TTPI = 2 \qquad \text{(C.3.18)}$$

TTPI = Time delay to increase transfer payments [Year]

$$TTPD = 5 \tag{C.3.19}$$

TTPD = Time delay to decrease transfer payments [Year]

Transfer payments mainly depend on availability of government financial reserves. Another factor, however, is the government's perception of its own popularity. If the government realizes that citizens are not satisfied with the current state of governance, a compensation in the form of transfer payments may be launched.

$$ADTP_t = NFTP \cdot LGR_t \cdot \max(1, FSTP_t) \tag{C.3.20}$$

ADTP	=	Desired transfer payments [$/Year]
NFTP (C.3.21)	=	Initial (normal) fraction of government financial reserves to be spent on transfer payments [1/Year]
LGR (C.3.13)	=	Government financial reserves [$]
FSTP (C.3.22)	=	Effect of government popularity on transfer payments [Dimensionless]

$$NFTP = 0.1 \tag{C.3.21}$$

NFTP = Initial (normal) fraction of government financial reserves to be spent on transfer payments [1/Year]

$$FSTP_t = PSTPM + \frac{2 \cdot (1 - PSTPM)}{LPPS_t^{PSTPS} + 1} \tag{C.3.22}$$

FSTP	=	Effect of government popularity on transfer payments
PSTPM (C.3.23)	=	Minimum of the function FSTP (effect of government popularity on transfer payments) [Dimensionless]
LPPS (C.3.25)	=	Perceived government popularity [Dimensionless]
PSTPS (C.3.29)	=	Slope of the function FSTP (effect of government popularity on transfer payments) [Dimensionless]

$$PSTPM = \frac{2 \cdot NFTP - PTFM}{NFTP} \tag{C.3.23}$$

PSTPM	=	Minimum of the function FSTP (effect of government popularity on transfer payments) [Dimensionless]
NFTP (C.3.21)	=	Initial (normal) fraction of government financial reserves to be spent on transfer payments [1/Year]
PTFM (C.3.24)	=	Maximum fraction of transfer payments [1/Year]

$$PTFM = 2 \cdot NFTP - (\frac{NFTP}{PTFL})^{PSTPR} \tag{C.3.24}$$

PTFM	=	Maximum fraction of transfer payments [1/Year]
NFTP (C.3.21)	=	Initial (normal) fraction of government financial reserves to be spent on transfer payments [1/Year]
PTFL (C.3.27)	=	Ultimate limit for fraction of transfer payments [1/Year]
PSTPR (C.3.28)	=	Parameter to change variation range of the function FSTP (effect of government popularity on transfer payments); the higher $PSTPR$ the wider the variation range [Dimensionless]

$$LPPS_t = LPPS_0 + \int_0^t \frac{LPS_\tau - LPPS_\tau}{TP} \cdot d\tau \tag{C.3.25}$$

$$LPPS_0 = 1 \tag{C.3.26}$$

LPPS	=	Perceived government popularity [Dimensionless]
LPS (C.7.11)	=	State popularity [Dimensionless]
TP (C.2.12)	=	Perception time delay [Year]

$$PTFL = 1 \tag{C.3.27}$$

PTFL = Ultimate limit for fraction of transfer payments [1/Year]

$$PSTPR = 2 \tag{C.3.28}$$

PSTPR = Parameter to change variation range of the function FSTP (effect of government popularity on transfer payments); the higher $PSTPR$ the wider the variation range [Dimensionless]

$$PSTPS = 1.5 \tag{C.3.29}$$

PSTPS = Slope of the function FSTP (effect of government popularity on transfer payments) [Dimensionless]

This function is meticulously designed so that the fraction of transfer payments never exceed a plausible range. Shape of the function with different selection of parameters is illustrated in Fig. C.3.2. Different shapes represent different transfer payments adjustment policies when reacting to the public opinion about the government. Some governments might be more responsive while others may be reluctant to change. Although financial restriction may force governments to limit their public expenditures and transfer payments, but it is assumed that government popularity higher than normal level will not cause a decline in such payments. This assumption could be changed for experimental purposes though.

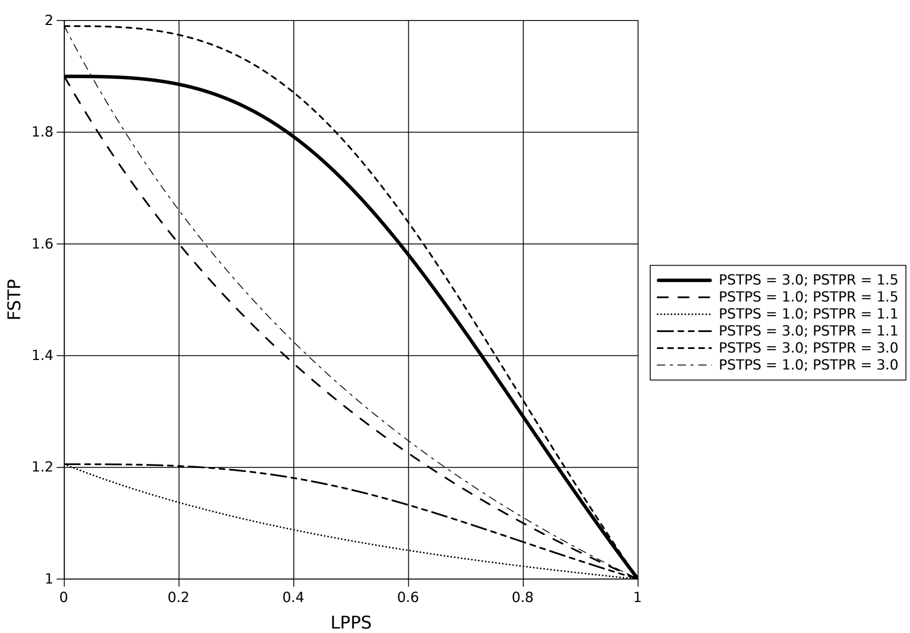

Figure C.3.2: Effect of government popularity on transfer payments

Although the government can have budget deficit for short- and mid-term but expenditure and investment must be covered by stream of revenues in the long-term[8]. Government revenues consist of tax and revenues from production of goods and services[9] which includes production and export of natural resources.

$$RGR_t = ATAX_t + AGO_t \tag{C.3.30}$$

RGR	=	Government revenues [$/Year]
ATAX (C.3.31)	=	Government tax revenues [$/Year]
AGO (C.4.27)	=	Total economic output of the government [$/Year]

Government production (AGO) will be explained in Section C.4. Here we focus on tax revenues. A fraction of taxable output (ATO) will be received by the government as tax revenues.

$$ATAX_t = ATR_t \cdot ATO_t \cdot FTAXC_t \tag{C.3.31}$$

ATAX	=	Government tax revenues [$/Year]
ATR (C.3.32)	=	Tax rate [Dimensionless]
ATO (C.3.42)	=	Taxable economic output [$/Year]
FTAXC (C.3.40)	=	Tax collectability [Dimensionless]

An important property of natural resource windfall aftermath—particularly for the case of developing (or underdeveloped) nations with democratic political systems—is that authorities receiving these revenues spend them to gain short-term political benefits (Robinson et al., 2006). For instance, they cut tax rates, or—as we saw earlier—increase public expenditures. Thus, tax rate in the model is a function of financial situation of the government. If government financial status improves, tax rate declines. The opposite could also happen but—as we will see soon—a rise in the tax rate does not necessarily translate into higher tax revenues. In fact, it requires a powerful, legitimate government to effectively collect taxes.

$$ATR_t = NTAXR \cdot FGRCT_t \tag{C.3.32}$$

ATR	=	Tax rate [Dimensionless]
NTAXR (C.3.33)	=	Initial (normal) tax rate [Dimensionless]
FGRCT (C.3.34)	=	Effect of government financial reserve coverage time on tax rate [Dimensionless]

[8]Despite Post-Keynesian theory of money which relaxes this assumption considering no limit for authorities to issue money (Wray, 2015), we believe that in reality, governments try to achieve—at least a long-run—balance for their budget.

[9]While this may not be significant for capitalist economies, resource-rich developing countries usually have a large government-owned production sector.

$$NTAXR = 0.08 \tag{C.3.33}$$

NTAXR = Initial (normal) tax rate [Dimensionless]

$$FGRCT_t = PGRCTM + \frac{(1 - PGRCTM) \cdot (1 + PGRCTX)}{PGRCTX + (AGRC_t/AGRC_0)^{PGRCTS}} \tag{C.3.34}$$

FGRCT	=	Effect of government financial reserve coverage time on tax rate [Dimensionless]
PGRCTM (C.3.35)	=	Minimum of the function $FGRCT$ (effect of government financial reserve coverage time on tax rate) [Dimensionless]
PGRCTX (C.3.36)	=	Maximum of the function $FGRCT$ (effect of government financial reserve coverage time on tax rate) [Dimensionless]
AGRC (C.3.39)	=	Government financial reserve coverage time [Year]
PGRCTS (C.3.38)	=	Slope of the function $FGRCT$ (effect of government financial reserve coverage time on tax rate) [Dimensionless]

$$PGRCTM = 0.8 \tag{C.3.35}$$

PGRCTM = Minimum of the function $FGRCT$ (effect of government financial reserve coverage time on tax rate) [Dimensionless]

$$PGRCTX = \frac{(PGRCTM - 1) \cdot NTAXR}{NTAXR - PTAXRM} \tag{C.3.36}$$

PGRCTX	=	Maximum of the function $FGRCT$ (effect of government financial reserve coverage time on tax rate) [Dimensionless]
PGRCTM (C.3.35)	=	Minimum of the function $FGRCT$ (effect of government financial reserve coverage time on tax rate) [Dimensionless]
NTAXR (C.3.33)	=	Initial (normal) tax rate [Dimensionless]
PTAXRM (C.3.37)	=	Maximum tax rate [Dimensionless]

$$PTAXRM = 0.4 \tag{C.3.37}$$

PTAXRM = Maximum tax rate [Dimensionless]

$$PGRCTS = 2 \tag{C.3.38}$$

PGRCTS = Slope of the function $FGRCT$ (effect of government financial reserve coverage time on tax rate) [Dimensionless]

$$AGRC_t = \frac{LGR_t}{RGE_t + RGI_t} \tag{C.3.39}$$

AGRC	=	Government financial reserve coverage time [Year]
LGR (C.3.13)	=	Government financial reserves [$]
RGE (C.3.14)	=	Government expenditure [$/Year]
RGI (C.3.6)	=	Government sector investment rate [$/Year]

Government financial coverage time—presented in Eq. C.3.39 indicates the length of time that the current financial reserves could cover normal expenses. In other words, it shows—given the current rate of its expenditures remain unchanged—length of time for which the government can run without having any revenues, borrowing, or issuing new money. If the coverage time increases, it shows that government's financial status is better than normal. In fact, Eq. C.3.34 is a decision rule that may differ from government to government. As Fig. C.3.3 shows, Eq. C.3.34 creates a wide range of possibilities so that many of the policy-making approaches could be examined. Note that slope of the function is the only changing parameter here. Minimum and maximum of the function also could vary to provide even a wider selection range. These variations are not depicted in C.3.3.

As it was mentioned before, tax revenues also depend on power of the government. A powerful government could collect taxes more effectively than a weak government. A tax collectability indicator is defined as a function of "state controlling power" to take this into account:

$$FTAXC_t = \frac{2/\left(1 + e^{-PTAXCC \cdot ASC_t}\right) - 1}{2/\left(1 + e^{-PTAXCC}\right) - 1} \tag{C.3.40}$$

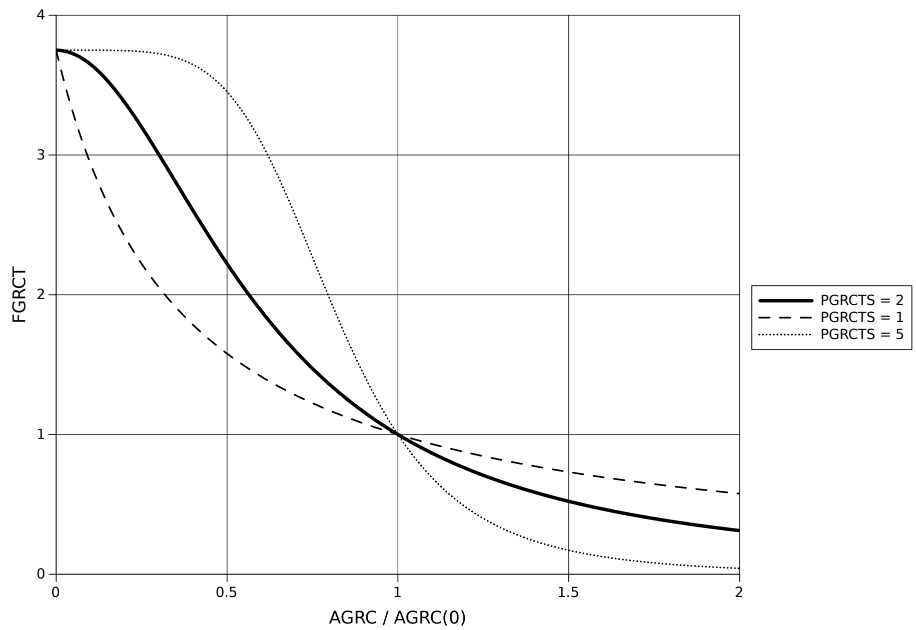

Figure C.3.3: Effect of government reserve coverage on tax rate

FTAXC	=	Tax collectability [Dimensionless]
PTAXCC (C.3.41)	=	Concaveness of the function $FTAXC$ (tax collectability) [Dimensionless]
ASC (C.7.35)	=	State controlling power [Dimensionless]

$$PTAXCC = \ln\left(\frac{1 + NTAXR/PTAXRM}{1 - NTAXR/PTAXRM}\right) \tag{C.3.41}$$

PTAXCC	=	Concaveness of the function $FTAXC$ (tax collectability) [Dimensionless]
NTAXR (C.3.33)	=	Initial (normal) tax rate [Dimensionless]
PTAXRM (C.3.37)	=	Maximum tax rate [Dimensionless]

This function and its variations are illustrated in Fig. C.3.4. Note that normal tax rate is the average tax rate that an average government could collect taxes at. On average, some tax aversion may happen. That is why, $FTAXC$ could go beyond 1 meaning that if the government is more powerful than normal, it can collect more than average tax rates.

Another important determinant of government tax revenues includes the

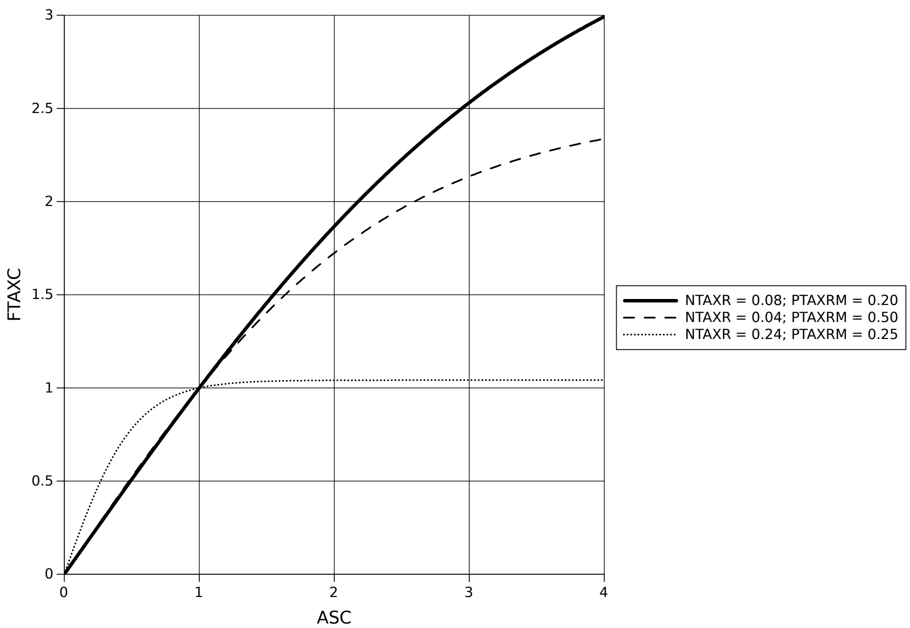

Figure C.3.4: Tax collectability multiplier

total taxable economic output. Taxable output includes those economic activities that could be traced and taxed by the government. Underground economy or those activities performed by the parasites are naturally excluded from this definition.

$$ATO_t = AO_t - APARI_t \tag{C.3.42}$$

ATO	=	Taxable economic output [$/Year]
AO (C.4.26)	=	Total output of the economy [$/Year]
APARI (C.4.5)	=	Total income of parasites [$/Year]

If government revenues are not sufficient to cover expenditures in the long-term new money would be issued and injected into the state reserves.

$$RM = \max\big(0, 1 - \frac{AGRC_t}{AGRC_0}\big) \cdot (RGE_t + RGI_t) \tag{C.3.43}$$

RM	=	Rate of issuing new money [$/Year]
AGRC (C.3.39)	=	Government financial reserve coverage time [Year]
RGE (C.3.14)	=	Government expenditure [$/Year]
RGI (C.3.6)	=	Government sector investment rate [$/Year]

C.4 Income

This section describes calculation of production and income in both private and government sectors. It also includes the way parasites exploit the economy. From these outputs, a rough measure of income equality will be computed. Although income equality might not be a complete measure of equality in general (Allison, 1978), but it is certainly a crucial factor. The goal of this chapter is not to investigate inequality issues so, only a simple measure of equality is used here. This sacrifice has been made for the compactness of the model. Equality measure in this model is shown by the ratio of wages paid to the working class to total income of the society (wages, profit, and parasite exploitations)[10].

$$AEQ_t = \frac{AW_t}{(APARI_t + AW_t + APP_t)} \tag{C.4.1}$$

AEQ	=	Income equality index [Dimensionless]
AW (C.4.2)	=	Total amount of wages paid to labor [$/Year]
APARI (C.4.5)	=	Total income of parasites [$/Year]
APP (C.4.25)	=	Private profit [$/Year]

$$AW_t = AGW_t + APW_t \tag{C.4.2}$$

AW (C.4.2)	=	Total amount of wages paid to labor [$/Year]
AGW (C.4.3)	=	Wages paid by the government [$/Year]
APW (C.4.4)	=	Wages paid by the private sector [$/Year]

$$AGW_t = (LGW_t + LCO_t) \cdot LWR_t \tag{C.4.3}$$

AGW	=	Wages paid by the government [$/Year]
LGW (C.1.15)	=	Workforce employed in the government sector [Person]
LCO (C.1.17)	=	Corrupt government officers: part of the government workforce who get involved in corrupt and illegal activities [Person]
LWR (C.5.4)	=	Average wage rate of the working class [$/(Year-Person)]

[10]For simplicity, it is assumed that wage is the only source of income for the working class while profit is the only source of income for the capital owners. For a more precise computation of income equality, a per capita index must be used. Nevertheless, the model does not trace class population so at this stage it will not be possible to have an equality index based on income per capita of different classes. Instead it is assumed that the relative population of classes remain more or less constant over the simulation period. With this assumption total income of classes could be sufficient to yield a rough approximation of equality.

$$APW_t = LPW_t \cdot LWR_t \tag{C.4.4}$$

APW	=	Wages paid by the private sector [$/Year]
LPW (C.1.40)	=	Workforce employed in the private sector [Person]
LWR (C.5.4)	=	Average wage rate of the working class [$/(Year-Person)]

Income of parasites depends on how much they can exploit the economy which is in turn a function of three factors: (a) how much is available for exploitation, (b) to what extent exploitation would be tolerated by authorities, and (3) how corrupted the control force is. It is also affected by participation of "corrupt officers" who would benefit from the exploitation. Exploitability is a geometric average[11] of these two factors. Relative weight of each factor in the average function could be changed by the parameter $PWEAE$.

$$APARI_t = AEPP_t \cdot (LP_t + LCO_t) \tag{C.4.5}$$

APARI	=	Total income of parasites [$/Year]
AEPP (C.4.6)	=	Average economic output that a parasite could exploit [$/(Year-Person)]
LP (C.1.42)	=	Parasites: part of workforce who do not work but enjoy consuming of others' production [Person]
LCO (C.1.17)	=	Corrupt government officers: part of the government workforce who get involved in corrupt and illegal activities [Person]

$$AEPP_t = NEPP \cdot LE_t \tag{C.4.6}$$

AEPP	=	Average economic output that a parasite could exploit [$/(Year-Person)]
NEPP (C.4.7)	=	Initial (normal) exploit per parasite [$/(Year-Person)]
LE (C.4.8)	=	Smoothed exploitability of the economy [Dimensionless]

$$NEPP = LWR_0 \tag{C.4.7}$$

[11] This is a geometric average because exploitability cannot happen—i.e. it must be zero—if either of the variables affecting it declines to zero. As an extreme example, if total economic output is zero for a particular year there would be nothing for the parasites to exploit regardless of the state control and the level of corruption. This is also true for the other variables: if the state is so powerful and effective it will not allow any instance of exploitation, notwithstanding economic productivity.

NEPP	=	Initial (normal) exploit per parasite [$/(Year-Person)]
LWR (C.5.4)	=	Average wage rate of the working class [$/(Year-Person)]

$$LE_t = 1 + \int_0^t \frac{AE_\tau - LE_\tau}{TEPP} d\tau \tag{C.4.8}$$

LE	=	Smoothed exploitability of the economy [Dimensionless]
AE (C.4.10)	=	Exploitability of the economy [Dimensionless]
TEPP (C.4.9)	=	Time to smooth economic output that a parasite could exploit [Year]

$$TEPP = 5 \tag{C.4.9}$$

TEPP	=	Time to smooth economic output that a parasite could exploit [Year]

$$AE_t = FRFE_t^{PWRAE} \cdot FEFE_t^{PWEAE} \cdot FCFE_t^{1-PWEAE-PWRAE} \cdot (1 + AOME_t) \tag{C.4.10}$$

AE	=	Exploitability of the economy [Dimensionless]
FEFE (C.4.18)	=	Effect of economic situation on exploitability [Dimensionless]
PWEAE (C.4.11)	=	Weight of economic constraints in exploitability function AE [Dimensionless]
FRFE (C.4.16)	=	Effect of corruption on exploitability [Dimensionless]
PWRAE (C.4.12)	=	Weight of corruption in exploitability function AE [Dimensionless]
FCFE (C.4.13)	=	Effect of state control on exploitability [Dimensionless]
AOME (C.4.22)	=	Chance of exploitability from oil revenues [Dimensionless]

$$PWEAE = 0.4 \tag{C.4.11}$$

PWEAE	=	Weight of economic constraints in exploitability function AE [Dimensionless]

$$PWRAE = 0.4 \tag{C.4.12}$$

PWRAE = Weight of corruption in exploitability function AE [Dimensionless]

As (effective) controlling power of the government increases, parasites will have less freedom to exploit the economy. Shape of this function and its variation range could be modified by the provided parameters [see Fig. C.4.1].

$$FCFE_t = \frac{PECVR + 2/\left(1 + e^{PECC \cdot ASC_t}\right)}{PECVR + 2/\left(1 + e^{PECC}\right)} \tag{C.4.13}$$

FCFC	=	Effect of state control on exploitability [Dimensionless]
PECVR (C.4.14)	=	Parameter to set range of variation for the function of exploitability from control [Dimensionless]
PECC (C.4.15)	=	Parameter to set convexness of the function of exploitability from control [Dimensionless]
ASC (C.7.35)	=	State controlling power [Dimensionless]

$$PECVR = 0.8 \tag{C.4.14}$$

PECVR = Slope of the function of exploitability from control [Dimensionless]

$$PECC = 3 \tag{C.4.15}$$

PECC = Parameter to set convexness of the function of exploitability from control [Dimensionless]

Corruption, to some extent, offsets the effect of the state control in two ways. First, "corrupt officers" do not contribute to the controlling mechanism. This per se reduces effectiveness of the state's ability to control the exploitation. This effect is already included in the state control though because state control excludes "corrupt officers." Second, since they have stake in it, "corrupt officers" try to maximize the exploitation. This effect is replicated by Eq. C.4.16 which is illustrated graphically in Fig. C.4.2.

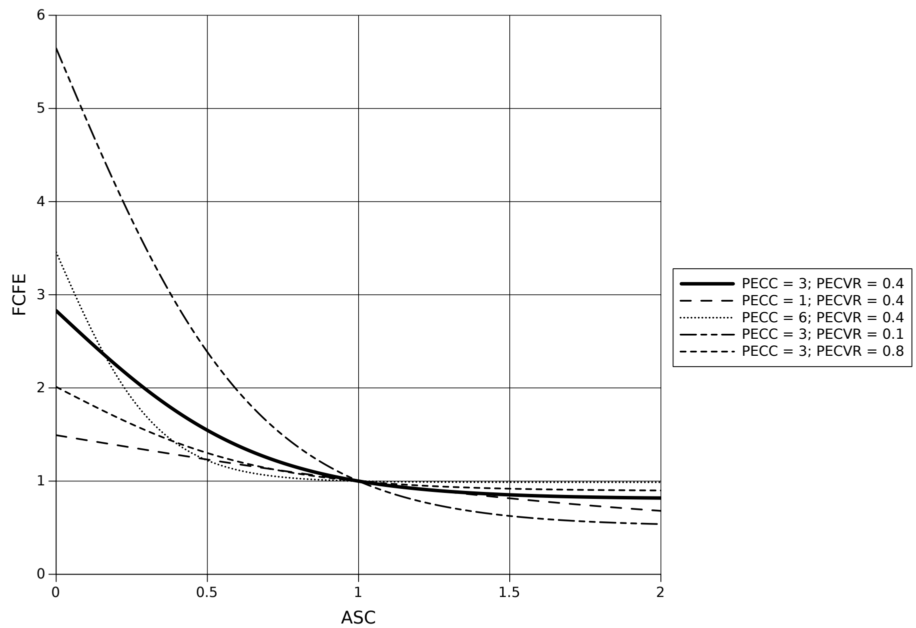

Figure C.4.1: Effect of state controlling power on exploitability

$$FRFE_t = (\frac{LCO_t + 2 \cdot LCO_0}{3 \cdot LCO_0})^{PRFE} \tag{C.4.16}$$

FRFE	=	Effect of corruption on exploitability [Dimensionless]
LCO (C.1.17)	=	Corrupt government officers: part of the government workforce who get involved in corrupt and illegal activities [Person]
PRFE (C.4.17)	=	Corruption elasticity of exploitability [Dimensionless]

$$PRFE = 1.5 \tag{C.4.17}$$

PRFE	=	Corruption elasticity of exploitability [Dimensionless]

As economy becomes richer, ceteris paribus, a greater opportunity would arise for parasite to exploit. Eq. C.4.18 captures this relationship.

$$FEFE_t = \frac{AO_t - APARI_t}{NO - NPARI}^{PEEC} \tag{C.4.18}$$

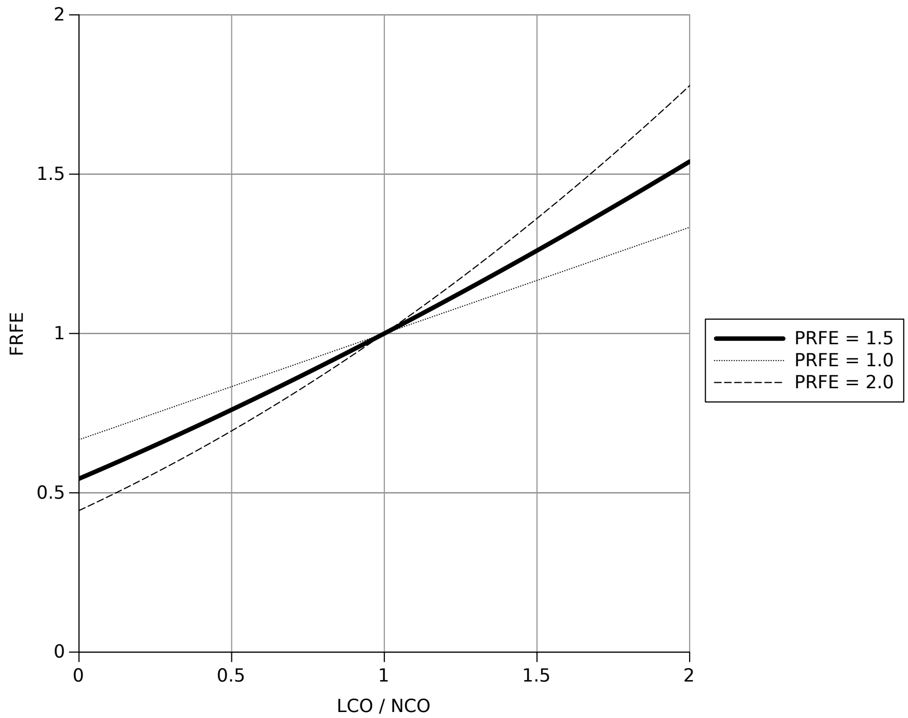

Figure C.4.2: Effect of corruption on exploitability

FEFE	=	Effect of economic situation on exploitability [Dimensionless]
AO (C.4.26)	=	Total output of the economy [$/Year]
NO (C.4.19)	=	Normal (initial) total output of the economy [$/Year]
APARI (C.4.5)	=	Total income of parasites [$/Year]
NPARI (C.4.20)	=	Normal (initial) total income of parasites [$/Year]
PEEC (C.4.21)	=	Parameter to set concaveness of the function of exploitability from adequacy of economic output [Dimensionless]

$$NO = NPO + NGO \tag{C.4.19}$$

NO	=	Normal (initial) total output of the economy [$/Year]
NPO (C.4.41	=	Initial (normal) private production [$/Year]
NGO (C.4.35)	=	Initial (normal) government production [$/Year]

$$NPARI = NEPP \cdot (NCO + NPAR) \tag{C.4.20}$$

NPARI	=	Normal (initial) total income of parasites [$/Year]
NEPP (C.4.7)	=	Initial (normal) exploit per parasite [$/(Year-Person)]
NCO (C.1.18)	=	Initial (normal) corrupt government officers [Person]
NPAR (C.1.43)	=	Initial (normal) parasites [Person]

$$PEEC = 1 \tag{C.4.21}$$

PEEC	=	Parameter to set concaveness of the function of exploitability from adequacy of economic output [Dimensionless]

Another source of exploitation is the natural resource revenue which provides a significant rent (Karl, 1997, 1999). So, as natural resource revenue increases, chance of exploitation increases too. This chance, nevertheless, could be affected by the institutional setting of the society. A society with "good" institutions could limit the exploitation of natural resource revenues (Mehlum et al., 2006). Eq. C.4.23 which is depicted in Fig. C.4.3 represent this assumption.

$$AOME_t = FOME_t \cdot \frac{AOEXP_t}{AO_t} \tag{C.4.22}$$

AOME	=	Chance of exploitability from oil revenues [Dimensionless]
FOME (C.4.23)	=	Effect of good institutions on exploitability of oil revenues [Dimensionless]
AOEXP (C.8.1)	=	Oil Export [$/Year]
AO (C.4.26)	=	Total output of the economy [$/Year]

$$FOME_t = \frac{5}{(\frac{LGI_t}{LGI_0})^{POME} + 4} \tag{C.4.23}$$

FOME	=	Effect of good institutions on exploitability of oil revenues [Dimensionless]
LGI (C.1.26)	=	Number of good institutions [Dimensionless]
POME (C.4.24)	=	Concaveness of the function $FOME$ [Dimensionless]

$$POME_t = 2 \tag{C.4.24}$$

POME = Concaveness of the function $FOME$ [Dimensionless]

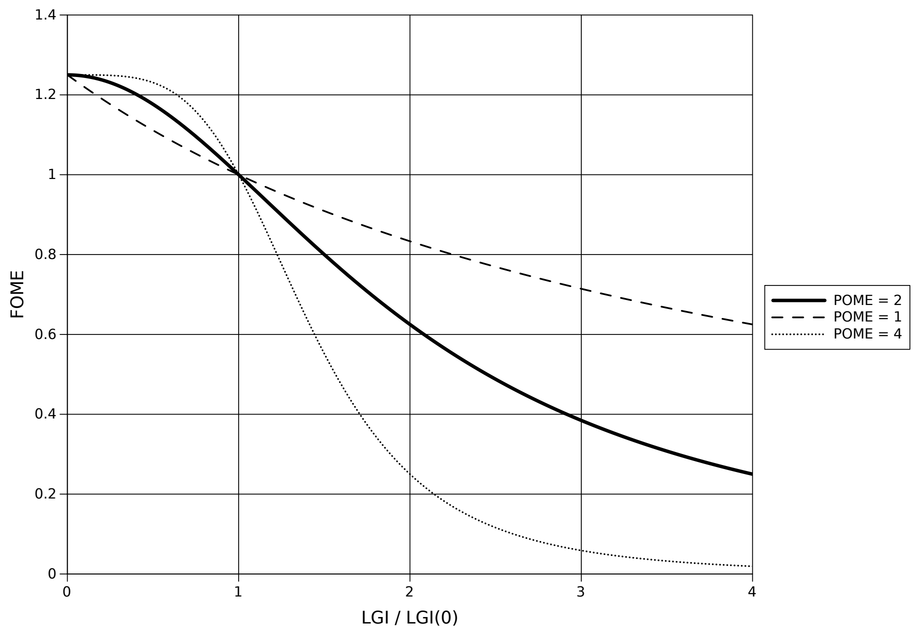

Figure C.4.3: Effect of good institutions on exploitability of oil revenues

As mentioned before, the only source of income for capital owners is the profit from production. Profit is simply the difference between production value and total wage which is paid to the labor.

$$APP_t = APO_t - APW_t \tag{C.4.25}$$

APP	=	Private profit [$/Year]
APO (C.4.39)	=	Total economic output of the private sector [$/Year]
APW (C.4.4)	=	Wages paid by the private sector [$/Year]

Total output of the economy consists of government and private production:

$$AO_t = AGO_t + APO_t \tag{C.4.26}$$

AO	=	Total output of the economy [$/Year]
AGO (C.4.27)	=	Total economic output of the government [$/Year]
APO (C.4.39)	=	Total economic output of the private sector [$/Year]

Goods and services produced in the economy are classified into two categories: traded and non-traded. This is to capture the impact of natural resource windfall on reallocation of production factors which results in decline of production of traded goods and services in favor of non-traded goods and services.

$$\begin{aligned} AGO_t =& LTPF_t \cdot AGPRO_t \cdot LTPI_t \cdot LEPTG_t \\ &+ (1 - LTPF_t) \cdot AGPRO_t \cdot LNTPI_t + AOEXP_t \end{aligned} \tag{C.4.27}$$

AGO	=	Total economic output of the government [$/Year]
LTPF (C.4.28)	=	Fraction of production capacity allocated to traded goods sector [Dimensionless]
AGPRO (C.4.34)	=	Production capacity in the government sector [$/Year]
LTPI (C.5.9)	=	Price index of traded goods [Dimensionless]
LEPTG (C.4.32)	=	Effect of experience on production of traded goods [Dimensionless]
LNTPI (C.5.21)	=	Price index of non-traded goods [Dimensionless]
AOEXP (C.8.1)	=	Oil Export [$/Year]

Relative price indexes in traded and non-traded sectors determine the fraction of production capacity that must be allocated to each sector. This reallocation, however, is subject to a time delay represented by $TRPF(C.4.31)$.

$$LTPF_t = LTPF_0 + \int_0^t \frac{ATPF_\tau - LTPF_\tau}{TRPF} \cdot d\tau \tag{C.4.28}$$
$$LTPF_0 = 1 - NNTPF$$

LTPF	=	Fraction of production capacity allocated to traded goods sector [Dimensionless]
NNTPF (C.4.29)	=	Initial (normal) fraction of production capacity allocated to non-traded goods sector [Dimensionless]
ATPF (C.4.30)	=	Indicated fraction of production capacity allocated to traded goods sector [Dimensionless]
TRPF (C.4.31)	=	Time delay to reallocate production factors [Year]

$$NNTPF = 0.6 \tag{C.4.29}$$

NNTPF = Initial (normal) fraction of production capacity allocated to non-traded goods sector [Dimensionless]

$$ATPF_t = \Big(1 - NNTPF\Big)^{(\frac{LNTPI_t}{LTPI_t})} \quad \text{(C.4.30)}$$

ATPF	=	Indicated fraction of production capacity allocated to traded goods sector [Dimensionless]
NNTPF (C.4.29)	=	Initial (normal) fraction of production capacity allocated to non-traded goods sector [Dimensionless]
LNTPI (C.5.21)	=	Price index of non-traded goods [Dimensionless]
LTPI (C.5.9)	=	Price index of traded goods [Dimensionless]

$$TRPF = 5 \quad \text{(C.4.31)}$$

TRPF = Time delay to reallocate production factors [Year]

One important aspect of the Dutch Disease theory that was particularly highlighted in the system dynamics literature (Mashayekhi, 1978; Moxnes, 1983) is that a reallocation of resources from traded goods to non-traded goods sector could significantly harm the economy due to the lost experience in the production of traded goods that might happen as a subsequent to the initial resource reallocation. As identified by van der Ploeg (2011), this is one of the explanations for the natural resource curse. A simple mechanism of experience accumulation/decumulation is employed to capture this phenomenon. As fraction of production capacity allocated to the traded sector increases, the experience increases beyond its normal (equilibrium) state through learning by doing process.

$$LEPTG_t = LEPTG_0 + \int_0^t \frac{\frac{LTPF_\tau}{1 - NNTPF} - LEPTG_\tau}{TLBD} \cdot d\tau \quad \text{(C.4.32)}$$
$$LEPTG_0 = 1$$

LEPTG	=	Effect of experience on production of traded goods [Dimensionless]
LTPF (C.4.28)	=	Fraction of production capacity allocated to traded goods sector [Dimensionless]
NNTPF (C.4.29)	=	Initial (normal) fraction of production capacity allocated to non-traded goods sector [Dimensionless]
TLBD (C.4.33)	=	Time delay to accumulate experience from production [Year]

$$TLBD = 10 \tag{C.4.33}$$

TLBD = Time delay to accumulate experience from production [Year]

Production capacity in the model is defined as a variation of Cobb-Douglas production function.

$$AGPRO_t = 0.5 \cdot NGO \cdot \frac{1 - LCRF_t}{1 - NCRF} \cdot (\frac{LGW_t}{NGW})^{PLE} \cdot \Big(1 + (\frac{AGRCAP_t}{NGC})^{PCE}\Big) \tag{C.4.34}$$

AGPRO	=	Production capacity in the government sector [$/Year]
NGO (C.4.35)	=	Initial (normal) government production [$/Year]
LCRF (C.7.40)	=	Fraction of government resources allocated to control means [Dimensionless]
NCRF (C.7.36)	=	Initial (normal) fraction of government resources allocated to control means [Dimensionless]
LGW (C.1.15)	=	Workforce employed in the government sector [Person]
NGW (C.1.16)	=	Initial (normal) government sector workforce [Person]
PLE (C.4.36)	=	Output elasticity of labor [Dimensionless]
AGRCAP (C.4.38)	=	Real capital in the government sector [$]
NGC (C.3.2)	=	Initial (normal) government capital [$]
PCE (C.4.37)	=	Output elasticity of capital [Dimensionless]

$$NGO = NWR \cdot NGW \tag{C.4.35}$$

NGO	=	Initial (normal) government production [$/Year]
NWR (C.5.2)	=	Initial (normal) average wage rate of the working class [$/(Year-Person)]
NGW (C.1.16)	=	Initial (normal) government sector workforce [Person]

$$PLE = 0.6 \tag{C.4.36}$$

PLE = Output elasticity of labor [Dimensionless]

$$PCE = 0.4 \tag{C.4.37}$$

PCE = Output elasticity of capital [Dimensionless]

$$AGRCAP_t = \frac{LTPF_t \cdot LGC_t}{LTPI_t} + \frac{(1 - LTPF_t) \cdot LGC_t}{LNTPI_t} \tag{C.4.38}$$

AGRCAP	=	Real capital in the government sector [$]
LTPF (C.4.28)	=	Fraction of production capacity allocated to traded goods sector [Dimensionless]
LGC (C.3.1)	=	Government capital [$]
LTPI (C.5.9)	=	Price index of traded goods [Dimensionless]
LNTPI (C.5.21)	=	Price index of non-traded goods [Dimensionless]

Production in the private sector uses the same format as the government production does. The only differences are exclusion of oil export $AOEXP$ from the private production and variations in some parameters.

$$\begin{aligned} APO_t =& LTPF_t \cdot APPRO_t \cdot LTPI_t \cdot LEPTG_t \\ &+ (1 - LTPF_t) \cdot APPRO_t \cdot LNTPI_t \end{aligned} \tag{C.4.39}$$

APO	=	Total economic output of the private sector [$/Year]
LTPF (C.4.28)	=	Fraction of production capacity allocated to traded goods sector [Dimensionless]
APPRO	=	Production capacity in the private sector [$/Year]
LTPI (C.5.9)	=	Price index of traded goods [Dimensionless]
LEPTG (C.4.32)	=	Effect of experience on production of traded goods [Dimensionless]
LTPF (C.4.28)	=	Fraction of production capacity allocated to traded goods sector [Dimensionless]
LNTPI (C.5.21)	=	Price index of non-traded goods [Dimensionless]

$$APPRO_t = 0.5 \cdot NPO \cdot (\frac{LPW_t}{NPW})^{PLE} \cdot \Big(1 + (\frac{APRCAP_t}{NPC})^{PCE}\Big) \tag{C.4.40}$$

APPRO	=	Production capacity in the private sector [$/Year]
NPO (C.4.41	=	Initial (normal) private production [$/Year]
LPW (C.1.40)	=	Workforce employed in the private sector [Person]
NPW (C.1.41)	=	Initial (normal) private sector workforce [Person]
APRCAP (C.4.42)	=	Real capital in the private sector [$]
NPC (C.2.2)	=	Initial (normal) private capital [$]
PCE (C.4.37)	=	Output elasticity of capital [Dimensionless]

$$NPO = 2 \cdot NWR \cdot NPW \tag{C.4.41}$$

NPO	=	Initial (normal) private production [$/Year]
NWR (C.5.2)	=	Initial (normal) average wage rate of the working class [$/(Year-Person)]
NPW (C.1.41)	=	Initial (normal) private sector workforce [Person]

$$APRCAP_t = \frac{LTPF_t \cdot LPC_t}{LTPI_t} + \frac{(1 - LTPF_t) \cdot LPC_t}{LNTPI_t} \tag{C.4.42}$$

APRCAP	=	Real capital in the private sector [$]
LPC (C.2.1)	=	Stock of private capital [$]
LTPF (C.4.28)	=	Fraction of production capacity allocated to traded goods sector [Dimensionless]
LTPI (C.5.9)	=	Price index of traded goods [Dimensionless]
LNTPI (C.5.21)	=	Price index of non-traded goods [Dimensionless]

Finally, the more the parasites earn the more attractive it becomes for others to follow their footsteps. So, attractiveness of such activities including rent seeking could be given by comparing parasite income and average labor wage.

$$AAP_t = \frac{AEPP_t}{LWR_t} \tag{C.4.43}$$

AAP	=	Attractiveness of being parasite [Dimensionless]
AEPP (C.4.6)	=	Average economic output that a parasite could exploit [$/(Year-Person)]
LWR (C.5.4)	=	Average wage rate of the working class [$/(Year-Person)]

C.5 Price & Wage

"Price & Wage" computes wage rate of the working class in the society as well as prices of good and services. Wage rate is determined by unemployment rate which is used as a proxy for the labor demand-supply ratio. As unemployment increases wage rates decline. In contrast, a decline in unemployment rate puts pressure on wage rates to increase. Wage elasticity of unemployment rate, nonetheless, could be controlled by the parameter PWS (wage stickiness). The base model assumes no wage stickiness though.

$$AWR_t = NWR \cdot (\frac{PNUR}{AUR_t})^{1-PWS} \tag{C.5.1}$$

AWR	=	Indicated wage rate of the working class [$/(Year-Person)]
NWR (C.5.2)	=	Initial (normal) average wage rate of the working class [$/(Year-Person)]
PNUR (C.1.49)	=	Natural unemployment rate [Dimensionless]
AUR (C.1.48)	=	Unemployment rate [Dimensionless]
PWS (C.5.3)	=	Wage stickiness [Dimensionless]

$$NWR = 4 \tag{C.5.2}$$

NWR	=	Initial (normal) average wage rate of the working class [$/(Year-Person)][12]

$$PWS = 0 \tag{C.5.3}$$

PWS	=	Wage stickiness (0 indicates no stickiness; 1 indicates absolute stickiness) [Dimensionless]

[12]Numerical value of this parameter is not of importance. What matters in our analysis is only the variables' qualitative changes of behavior over time.

It takes time for wage rates to adjusts themselves with the market changes. Also note that the average wage rate could increase (RWI: C.5.5) faster than it decreases (RWD: C.5.7) due to wage down stickiness ($PWDS$: C.5.8). Base model assumes no down stickiness but different levels of stickiness could be tested as alternative scenarios.

$$LWR_t = LWR_0 + \int_0^t (RWI_\tau - RWD_\tau) \cdot d\tau \tag{C.5.4}$$
$$LWR_0 = NWR$$

LWR	=	Average wage rate of the working class [$/(Year-Person)]
NWR (C.5.2)	=	Initial (normal) average wage rate of the working class [$/(Year-Person)]
RWI (C.5.5)	=	Wage increase rate [$\$/(Person \cdot Year^2)$]
RWD (C.5.7)	=	Wage decrease rate [$\$/(Person \cdot Year^2)$]

$$RWI_t = \frac{\max(0, AWR_t - LWR_t)}{TWA} \tag{C.5.5}$$

RWI	=	Wage increase rate [$\$/(Person \cdot Year^2)$]
AWR (C.5.1)	=	Indicated wage rate of the working class [$/(Year-Person)]
LWR (C.5.4)	=	Average wage rate of the working class [$/(Year-Person)]
TWA (C.5.6)	=	Time delay for wage rates to adjust [Year]

$$TWA = 5 \tag{C.5.6}$$

TWA	=	Time delay for wage rates to adjust [Year]

$$RWD_t = (1 - PWDS) \cdot \frac{-MIN(0, AWR_t - LWR_t)}{TWA} \tag{C.5.7}$$

RWD	=	Wage decrease rate [$\$/(Person \cdot Year^2)$]
PWDS (C.5.3)	=	Wage down stickiness [Dimensionless]
AWR (C.5.1)	=	Indicated wage rate of the working class [$/(Year-Person)]
LWR (C.5.4)	=	Average wage rate of the working class [$/(Year-Person)]
TWA (C.5.6)	=	Time delay for wage rates to adjust [Year]

$$PWDS = 0 \tag{C.5.8}$$

PWDS	=	Wage down stickiness (0 indicates no stickiness; 1 indicates absolute stickiness) [Dimensionless]

This section also describes the mechanism of changes in price index in two markets: traded and non-traded goods and services. The mechanism is similar in both markets. Hence, one of them only is explained here. Price index adjusts itself with the indicated (instantaneous) price, but with a delay. Furthermore, average price could increase ($RTRPI$: C.5.10) faster than it decreases ($RTRPD$: C.5.11) due to price down stickiness ($PWDS$: C.5.8). Base model assumes no down stickiness but different levels of stickiness could be tested as alternative scenarios. Initial price is set to the base price index i.e. 1.

$$LTPI_t = LTPI_0 + \int_0^t (RTRPI_\tau - RTRPD_\tau) \cdot d\tau \tag{C.5.9}$$
$$LTPI_0 = 1$$

LTPI	=	Price index of traded goods [Dimensionless]
RTRPI (C.5.10)	=	Increase rate of price of traded goods and services [1/Year]
RTRPD (C.5.11)	=	Decrease rate of price of traded goods and services [1/Year]

$$RTRPI_t = \frac{\max(0, ATPI_t - LTPI_t)}{TPA} \tag{C.5.10}$$

RTRPI	=	Increase rate of price of traded goods and services [1/Year]
ATPI (C.5.14)	=	Indicated price index of traded goods and services [Dimensionless]
LTPI (C.5.9)	=	Price index of traded goods [Dimensionless]
TPA (C.5.9)	=	Time delay for prices to adjust [Year]

$$RTRPD_t = (1 - PTPDS) \cdot \frac{-\min(0, ATPI_t - LTPI_t)}{TPA} \tag{C.5.11}$$

RTRPD	=	Decrease rate of price of traded goods and services [1/Year]
PTPDS (C.5.12)	=	Down stickiness of traded goods price [Dimensionless]
ATPI (C.5.14)	=	Indicated price index of traded goods and services [Dimensionless]
LTPI (C.5.9)	=	Price index of traded goods [Dimensionless]
TPA (C.5.9)	=	Time delay for prices to adjust [Year]

$$PTPDS = 0 \tag{C.5.12}$$

PTPDS	=	Down stickiness of traded goods price (0 indicates no stickiness; 1 indicates absolute stickiness) [Dimensionless]

$$TPA = 5 \tag{C.5.13}$$

TPA	=	Time delay for prices to adjust [Year]

Indicated price is determined by supply-demand ratio. A general price stickiness ($PTPS$: C.5.15) could also be applied. Base model assumes no price stickiness though.

$$ATPI_t = (\frac{RTD_t}{RTS})^{1-PTPS} \tag{C.5.14}$$

ATPI	=	Indicated price index of traded goods and services [Dimensionless]
RTD (C.5.16)	=	Demand for traded goods [$/Year]
RTS (C.5.18)	=	Supply of traded goods [$/Year]
PTPS (C.5.15)	=	Stickiness of traded goods price [Dimensionless]

$$PTPS = 0 \tag{C.5.15}$$

PTPS	=	Stickiness of traded goods price (0 indicates no stickiness; 1 indicates absolute stickiness) [Dimensionless]

Demand for traded goods and services is a simple equation based on national accounting definition.

$$RTD_t = ARNOE_t + (1 - NNTPF) \cdot \frac{RGI_t + RPI_t + APC_t}{LTPI_t} \tag{C.5.16}$$

RTD	=	Demand for traded goods [$/Year]
ARNOE (C.5.17)	=	Real non-oil exports [$/Year]
NNTPF (C.4.29)	=	Initial (normal) fraction of production capacity allocated to non-traded goods sector [Dimensionless]
RGI (C.3.6)	=	Government sector investment rate [$/Year]
RPI (C.2.8)	=	Private sector investment rate [$/Year]
APC (C.2.23)	=	Private consumption [$/Year]
LTPI (C.5.9)	=	Price index of traded goods [Dimensionless]

$$ARNOE_t = \frac{AEXP_t - AOEXP_t}{LER_t} \tag{C.5.17}$$

ARNOE	=	Real non-oil exports [$/Year]
AEXP (C.6.11)	=	Exports [$/Year]
AOEXP (C.8.1)	=	Oil exports [$/Year]
LER (C.6.1)	=	Exchange rate [Dimensionless]

Supply of traded goods and services include domestic supply and imports.

$$RTS_t = ATPRO_t + ARIMP_t \tag{C.5.18}$$

RTS	=	Supply of traded goods [$/Year]
ATPRO (C.5.19)	=	Production of traded goods and services [$/Year]
ARIMP (C.5.20)	=	Real imports [$/Year]

$$ATPRO_t = (APPRO_t + AGPRO_t) \cdot LTPF_t \cdot LEPTG_t \tag{C.5.19}$$

ATPRO	=	Production of traded goods and services [$/Year]
APPRO (C.4.40)	=	Production capacity in the private sector [$/Year]
AGPRO (C.4.34)	=	Production capacity in the government sector [$/Year]
LTPF (C.4.28)	=	Fraction of production capacity allocated to traded goods sector [Dimensionless]
LEPTG (C.4.32)	=	Effect of experience on production of traded goods [Dimensionless]

$$ARIMP_t = \frac{AIMP_t}{LER_t} \tag{C.5.20}$$

ARIMP	=	Real imports [$/Year]
AIMP (C.6.19)	=	Imports [$/Year]
LER (C.6.1)	=	Exchange rate [Dimensionless]

As it was mentioned earlier, price adjustment in the non-traded goods market is similar to the traded-goods'. Major difference, however, is that unlike what we have seen for the traded sector, international trade is irrelevant for non-traded market. In other words for such market, supply ($RNTS$: C.5.28) excludes imports and exports are excluded from demand ($RNTD$: C.5.27).

$$LNTPI_t = LNTPI_0 + \int (RNTPI_\tau - RNTPD_\tau) \cdot d\tau \tag{C.5.21}$$

$$LNTPI_0 = 1$$

LNTPI	=	Price index of non-traded goods [Dimensionless]
RNTPI (C.5.22)	=	Increase rate of price of non-traded goods and services [1/Year]
RNTPD (C.5.23)	=	Decrease rate of price of non-traded goods and services [1/Year]

$$RNTPI_t = \frac{\max(0, ANTPI_t - LNTPI_t)}{TPA} \tag{C.5.22}$$

RNTPI	=	Increase rate of price of non-traded goods and services [1/Year]
ANTPI (C.5.25)	=	Indicated price index of non-traded goods and services [Dimensionless]
LNTPI (C.5.21)	=	Price index of non-traded goods [Dimensionless]
TPA (C.5.9)	=	Time delay for prices to adjust [Year]

$$RNTPD_t = (1 - PNTPDS) \cdot \frac{-MIN(0, ANTPI - LNTPI)}{TPA} \tag{C.5.23}$$

RNTPD	=	Decrease rate of price of non-traded goods and services [1/Year]
PNTPDS (C.5.24)	=	Down stickiness of non-traded goods price [Dimensionless]
ANTPI (C.5.25)	=	Indicated price index of non-traded goods and services [Dimensionless]
LNTPI (C.5.21)	=	Price index of non-traded goods [Dimensionless]
TPA (C.5.9)	=	Time delay for prices to adjust [Year]

$$PNTPDS = 0 \tag{C.5.24}$$

PNTPDS = Down stickiness of non-traded goods price (0 indicates no stickiness; 1 indicates absolute stickiness) [Dimensionless]

$$ANTPI_t = (\frac{RNTD_t}{RNTS_t})^{1-PNTPS} \tag{C.5.25}$$

ANTPI	=	Indicated price index of non-traded goods and services [Dimensionless]
RNTD (C.5.27)	=	Demand for non-traded goods [$/Year]
RNTS (C.5.28)	=	Supply of non-traded goods [$/Year]
PNTPS (C.5.26)	=	Stickiness of non-traded goods price (0 indicates no stickiness; 1 indicates absolute stickiness) [Dimensionless]

$$PNTPS = 0 \tag{C.5.26}$$

PNTPS = Stickiness of non-traded goods price [Dimensionless]

$$RNTD_t = NNTPF \cdot \frac{RGI_t + RPI_t + APC_t}{LNTPI_t} \tag{C.5.27}$$

RNTD	=	Demand for non-traded goods [$/Year]
NNTPF (C.4.29)	=	Initial (normal) fraction of production capacity allocated to non-traded goods sector [Dimensionless]
RGI (C.3.6)	=	Government sector investment rate [$/Year]
RPI (C.2.8)	=	Private sector investment rate [$/Year]
APC (C.2.23)	=	Private consumption [$/Year]
LNTPI (C.5.21)	=	Price index of non-traded goods [Dimensionless]

$$RNTS_t = (APPRO_t + AGPRO_t) \cdot (1 - LTPF_t) \tag{C.5.28}$$

RNTS	=	Supply of non-traded goods [$/Year]
APPRO (C.4.40)	=	Production capacity in the private sector [$/Year]
AGPRO (C.4.34)	=	Production capacity in the government sector [$/Year]
LTPF (C.4.28)	=	Fraction of production capacity allocated to traded goods sector [Dimensionless]

C.6 Foreign Exchange

In this section we discuss how the foreign exchange rate and its apparatus are captured in the model. Foreign exchange rate does not change spontaneously in the model but with a delay. The model also can take symmetric and down stickiness of foreign exchange rate, the base model does not include this assumption though.

$$LER_t = LER_0 + \int_0^t (RERI_\tau - RERD_\tau) \cdot d\tau \tag{C.6.1}$$
$$LER_0 = 1$$

LER	=	Foreign exchange rate [Dimensionless]
RERI (C.6.2)	=	Exchange rate increase rate [1/Year]
RERD (C.6.3)	=	Exchange rate decrease rate [1/Year]

$$RERI_t = \frac{\max(0, AER_t - LER_t)}{TPA} \tag{C.6.2}$$

RERI	=	Exchange rate increase rate [1/Year]
AER (C.6.5)	=	Indicated exchange rate [Dimensionless]
LER (C.6.1)	=	Foreign exchange rate [Dimensionless]
TPA (C.5.13)	=	Time delay for prices to adjust [Year]

$$RERD_t = (1 - PDSER) \cdot \frac{-\min(0, AER_t - LER_t)}{TPA} \tag{C.6.3}$$

RERD	=	Exchange rate decrease rate [1/Year]
PDSER (C.6.4)	=	Down stickiness of exchange rate [Dimensionless]
AER (C.6.5)	=	Indicated exchange rate [Dimensionless]
LER (C.6.1)	=	Foreign exchange rate [Dimensionless]
TPA (C.5.13)	=	Time delay for prices to adjust [Year]

$$PDSER = 0 \tag{C.6.4}$$

PDSER	=	Down stickiness of exchange rate [Dimensionless]

Foreign exchange rate could be affected by many political and economic factors. Particularly, Mashayekhi (1991) examines the dynamics of foreign exchange in an oil exporting country. In this model, however, the main factor influencing the exchange rate is the balance between supply and demand of foreign exchange in the domestic economy. This is represented by AEC (foreign exchange coverage time) which indicates adequacy of foreign exchange reserves to cover current level of imports (and any other international financial obligation).

$$AER_t = (\frac{NEC}{AEC_t})^{1-PSER} \tag{C.6.5}$$

AER	=	Indicated exchange rate [Dimensionless]
NEC (C.6.6)	=	Initial (normal) foreign exchange coverage time [Year]
AEC (C.6.8)	=	Coverage time of foreign exchange reserves [Year]
PSER (C.6.7)	=	Exchange rate stickiness [Dimensionless]

$$NEC = 2 \cdot \frac{NFE}{NT} \tag{C.6.6}$$

NEC	=	Initial (normal) foreign exchange coverage time [Year]
NFE (C.6.10)	=	Initial (normal) level of foreign exchange reserves [$]
NT (C.6.13)	=	Initial (normal) international trade [$/Year]

$$PSER = 0 \tag{C.6.7}$$

PSER	=	Exchange rate stickiness [Dimensionless]

$$AEC_t = \frac{LFE_t}{AIMP_t} \tag{C.6.8}$$

AEC	=	Coverage time of foreign exchange reserves [Year]
LFE (C.6.9)	=	Level of foreign exchange reserves [$]
AIMP (C.6.19)	=	Imports [$/Year]

Foreign exchange reserves is a stock that accumulates inflow of exchange that is gained through international transactions and declines though payments the country has to make for imports on any other international obligation.

$$LFE_t = LFE_0 + \int_0^t (AEXP_\tau - AIMP_\tau - RNDP_\tau) \cdot d\tau \tag{C.6.9}$$
$$LFE_0 = NFE$$

LFE	=	Level of foreign exchange reserves [$]
NFE (C.6.10)	=	Initial (normal) level of foreign exchange reserves [$]
AEXP (C.6.11)	=	Exports [$/Year]
AIMP (C.6.19)	=	Imports [$/Year]
RNDP (C.6.28)	=	Net foreign debt payment [$/Year]

$$NFE = 30000 \tag{C.6.10}$$

NFE = Initial (normal) level of foreign exchange reserves [$][13]

Exports are made based on the desired export but they are also limited by international trade capacity.

$$AEXP_t = ADEXP_t \cdot LER_t \cdot FTCM_t + AOEXP_t \tag{C.6.11}$$

AEXP	=	Exports [$/Year]
ADEXP (C.6.12)	=	Desired export [$/Year]
LER (C.6.1)	=	Foreign exchange rate [Dimensionless]
FTCM (C.6.14)	=	Multiplier for adequacy of trade capacity [Dimensionless]
AOEXP (C.8.1)	=	Oil Export [$/Year]

[13]Absolute numerical value of this parameter is not of importance. What matters is its relative value to other parameters of the model. In fact, we are only interested in qualitative changes of variables over time not their quantitative values.

Desired export is a function of real exchange rate. A depreciation of real exchange rate encourages exports and vice versa.

$$ADEXP_t = 0.5 \cdot NT \cdot \frac{LER_t}{LTPI_t} \tag{C.6.12}$$

ADEXP	=	Desired export [$/Year]
NT (C.6.13)	=	Initial (normal) international trade [$/Year]
LER (C.6.1)	=	Foreign exchange rate [Dimensionless]
LTPI (C.5.9)	=	Price index of traded goods [Dimensionless]

$$NT = 6000 \tag{C.6.13}$$

NT = Initial (normal) international trade [$/Year][14]

International trade requires various types of transportation infrastructure including harbors, airports, transit highways, etc. as well as facilities such as border customs and trade institutions. Inadequacy of such foundations may limit international trade. Eq. C.6.14 imposes such limitation. Variations of this function are depicted in Fig. C.6.1.

$$FTCM_t = \min\Big(1, (1 + PTCM) \cdot \frac{LTC_t/ADT_t}{\big(PTCM + LTC_t/ADT_t\big)}\Big) \tag{C.6.14}$$

FTCM	=	Multiplier for adequacy of trade capacity [Dimensionless]
PTCM (C.6.15)	=	Concaveness of the function $FTCM$ (Multiplier for adequacy of trade capacity) [Dimensionless]
LTC (C.6.16)	=	Trade capacity [$/Year]
ADT (C.6.18)	=	Desired trade [$/Year]

$$PTCM = 4 \tag{C.6.15}$$

PTCM = Concaveness of the function $FTCM$ (Multiplier for adequacy of trade capacity) [Dimensionless]

[14] Absolute numerical value of this parameter is not of importance. What matters is its relative value to other parameters of the model. In fact, we are only interested in qualitative changes of variables over time not their quantitative values.

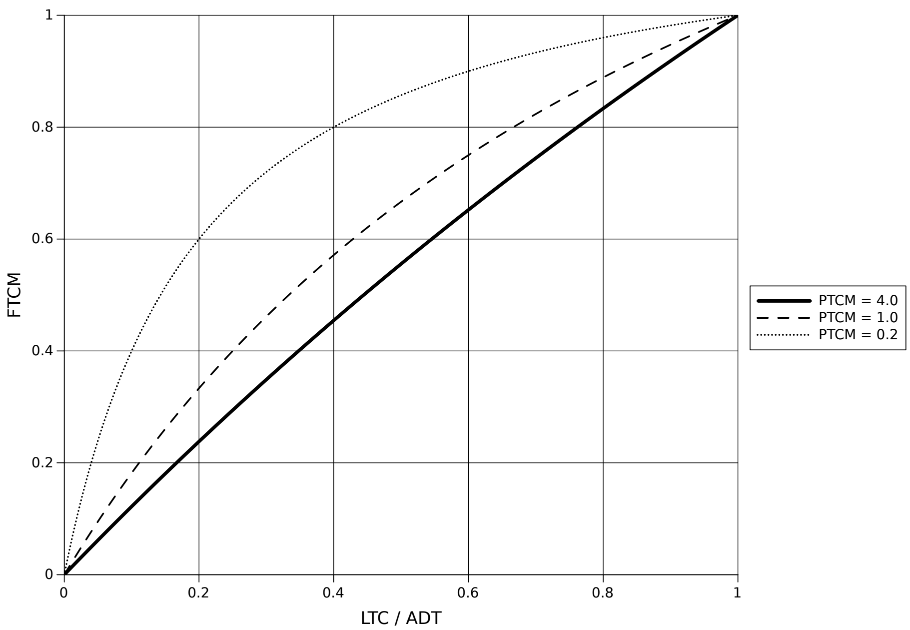

Figure C.6.1: Effect of trade capacity on international trade

Trade capacity (infrastructure) needs time to develop. So, we have:

$$LTC_t = LTC_0 + \int_0^t \frac{ADT_\tau - LTC_\tau}{TTCA} \cdot d\tau \qquad \text{(C.6.16)}$$

$$LTC_0 = NT$$

LTC	=	Trade capacity [$/Year]
NT (C.6.13)	=	Initial (normal) international trade [$/Year]
ADT (C.6.18)	=	Desired trade [$/Year]
TTCA (C.6.17)	=	Time delay to adjust trade capacity [Year]

$$TTCA = 5 \qquad \text{(C.6.17)}$$

TTCA = Time delay to adjust trade capacity [Year]

$$ADT_t = ADEXP_t + ADIMP_t \qquad \text{(C.6.18)}$$

ADT	=	Desired trade [$/Year]
ADEXP (C.6.12)	=	Desired export [$/Year]
ADIMP (C.6.22)	=	Desired imports [$/Year]

In addition to trade capacity constraints, adequacy of foreign exchange reserves impose another limitation on imports.

$$AIMP_t = ADIMP_t \cdot LER_t \cdot FTCM_t \cdot FEA_t \tag{C.6.19}$$

AIMP	=	Imports [$/Year]
ADIMP (C.6.22)	=	Desired imports [$/Year]
LER (C.6.1)	=	Foreign exchange rate [Dimensionless]
FTCM (C.6.14)	=	Multiplier for adequacy of trade capacity [Dimensionless]
FEA (C.6.20)	=	Foreign exchange availability indicator [Dimensionless]

Availability of foreign exchange is presented by Eq. C.6.20 which in terms of shape is similar to Eq. C.6.14 above.

$$FEA_t = (1 + PEA) \cdot \frac{LFE_t/NFE}{PEA + LFE_t/NFE} \tag{C.6.20}$$

FEA	=	Foreign exchange availability indicator [Dimensionless]
PEA (C.6.21)	=	Concaveness of the function FEA (foreign exchange availability indicator) [Dimensionless]
LFE (C.6.9)	=	Level of foreign exchange reserves [$]
NFE (C.6.10)	=	Initial (normal) level of foreign exchange reserves [$]

$$PEA = 0.5 \tag{C.6.21}$$

PEA	=	Concaveness of the function FEA (foreign exchange availability indicator) [Dimensionless]

Appreciation of real exchange rate encourages imports:

$$ADIMP_t = LNIMP_t \cdot \frac{LTPI_t}{LER_t} \tag{C.6.22}$$

ADIMP	=	Desired imports [$/Year]
LNIMP (C.6.23)	=	Normal imports [$/Year]
LTPI (C.5.9)	=	Price index of traded goods [Dimensionless]
LER (C.6.1)	=	Foreign exchange rate [Dimensionless]

According to Mashayekhi (1998), societies could become accustomed to certain levels of imports. While import dependency could easily expand, it would be relatively more difficult to reduce that level of dependency. To capture this phenomenon a normal level of import is defined in the model that dynamically adapts to the current level of imports. This normal import increases faster than it declines:

$$LNIMP_t = LNIMP_0 + \int_0^t (RNII_\tau - RNID_\tau) \cdot d\tau \qquad \text{(C.6.23)}$$

$$LNIMP_0 = 0.5 \cdot NT$$

LNIMP	=	Normal imports [$/Year]
NT (C.6.13)	=	Initial (normal) international trade [$/Year]
RNII (C.6.24)	=	Normal imports increase rate [$/($Year^2$)]
RNID (C.6.25)	=	Normal imports decrease rate [$/($Year^2$)]

$$RNII_t = \frac{\max(0, AIMP_t - LNIMP_t)}{TNII} \qquad \text{(C.6.24)}$$

RNII	=	Normal imports increase rate [$/($Year^2$)]
AIMP (C.6.19)	=	Imports [$/Year]
LNIMP (C.6.23)	=	Normal imports [$/Year]
TNII (C.6.26)	=	Time delay for normal imports to rise [Year]

$$RNID_t = \frac{-\min(0, AIMP_t - LNIMP_t)}{TNID} \qquad \text{(C.6.25)}$$

RNID	=	Normal imports decrease rate [$/($Year^2$)]
AIMP (C.6.19)	=	Imports [$/Year]
LNIMP (C.6.23)	=	Normal imports [$/Year]
TNID (C.6.27)	=	Time delay for normal imports to decline [Year]

$$TNII = 2 \qquad \text{(C.6.26)}$$

TNII = Time delay for normal imports to rise [Year]

$$TNID = 5 \qquad \text{(C.6.27)}$$

TNID = Time delay for normal imports to decline [Year]

Finally, if the country is short of foreign exchange they can borrow from international financial markets. Nevertheless, interest must be paid on the funds that are borrowed. These funds add to the foreign exchange reserves, as we saw earlier so that imports or other obligations could be financed. Note that $RNDP$ (C.6.28) could accept both positive and negative values. Positive values represent a net payment which deducts from foreign exchange reserves. Negative values, in contrast, represent a net yield that could be either from a fund that is borrowed or from interest earnings—the latter happens when LD (international debt C.6.31) is negative.

$$RNDP_t = RDP_t - RB_t \tag{C.6.28}$$

RNDP	=	Net foreign debt payment [$/Year]
RDP (C.6.29)	=	Foreign debt payments [$/Year]
RB (C.6.32)	=	Foreign borrowing rate [$/Year]

Foreign debt payments, as explained above, can be positive or negative depending on level of debt. Negative debt indicates financial assets that could generate a stream of foreign exchange revenues for the country.

$$RDP_t = \frac{LD_t}{TDP} \tag{C.6.29}$$

RDP	=	Foreign debt payments [$/Year]
LD (C.6.31)	=	International debt [$]
TDP (C.6.30)	=	Foreign debt payment time [Year]

$$TDP = 20 \tag{C.6.30}$$

TDP = Foreign debt payment time [Year]

Initial level of debt is assumed to be zero. This level could increase (decrease) if money is borrowed (lent), interest is paid (received), or when the principal that is lent (borrowed) is paid back.

$$LD_t = LD_0 \int_0^t (RB_\tau + RFIR_\tau - RDP_\tau) \cdot d\tau \tag{C.6.31}$$

$$LD_0 = 0$$

LD	=	International debt [$]
RB (C.6.32)	=	Foreign borrowing rate [$/Year]
RFIR (C.6.35)	=	Foreign interest revenues [$/Year]
RDP (C.6.29)	=	Foreign debt payments [$/Year]

Borrowing depends on the availability of foreign exchange and level of debt. If the exchange availability is low, the country borrows more and vice versa. As the level of debt increases borrowing becomes more and more difficult. This is shown by the Eq. C.6.34.

$$RB_t = \frac{NFE}{TFT} \cdot \left(1 - \sqrt[10]{\frac{AEC_t}{NEC}}\right) \cdot FDB_t \tag{C.6.32}$$

RB	=	Foreign borrowing rate [$/Year]
NFE (C.6.10)	=	Initial (normal) level of foreign exchange reserves [$]
TFT (C.6.33)	=	Foreign transaction time delay [Year]
AEC (C.6.8)	=	Coverage time of foreign exchange reserves [Year]
NEC (C.6.6)	=	Initial (normal) foreign exchange coverage time [Year]
FDB (C.6.34)	=	Effect of foreign debt on borrowing [Dimensionless]

$$TFT = 1 \tag{C.6.33}$$

TFT	=	Foreign transaction time delay [Year]

$$FDB = \frac{1}{1 + \frac{\max 0, LD_t}{NFE}} \tag{C.6.34}$$

FDB	=	Effect of foreign debt on borrowing [Dimensionless]
NFE (C.6.10)	=	Initial (normal) level of foreign exchange reserves [$]
LD (C.6.31)	=	International debt [$]

It is assumed that interest rate in international market is constant. This is not true in reality. However, factors that affect this rate are outside of the model's boundary. Thus, inclusion of these factors only adds to the model complexity but not much value to our analysis.

$$RFIR_t = LD_t \cdot PIR \tag{C.6.35}$$

RFIR	=	Foreign interest revenues [$/Year]
LD (C.6.31)	=	International debt [$]
PIR (C.6.36)	=	Average interest rate [1/Year]

$$PIR = 0.01 \tag{C.6.36}$$

PIR	=	Average interest rate [1/Year]

C.7 State Power & Control

This section describes the equations in the module of "state power and control." Political power of the state is a stock that approaches to an indicated level of power—explained further below—but with a delay.

$$LSP_t = LSP_0 + \int_0^t \frac{ASP_\tau - LSP_\tau}{TPCH} \cdot d\tau \tag{C.7.1}$$
$$LSP_0 = NSP$$

LSP	=	State political power [Dimensionless]
NSP (C.7.2)	=	Initial (normal) state political power [Dimensionless]
ASP (C.7.5)	=	Indicated state political power [Dimensionless]
TPCH (C.7.4)	=	Time delay for political power to change [Year]

$$NSP = 1 - \frac{1}{e^{PSPE}} \tag{C.7.2}$$

NSP	=	Initial (normal) state political power [Dimensionless]
PSPE (C.7.3)	=	Elasticity of state political power [Dimensionless]

$$PSPE = 1 \tag{C.7.3}$$

PSPE	=	Elasticity of state political power [Dimensionless]

$$TPCH = 5 \tag{C.7.4}$$

TPCH	=	Time delay for political power to change [Year]

The indicated level of political power depends on its popularity and utility of political power in the society. This assumption should be adequate for democratic as well as non-democratic political systems. Elasticity of political system, frequency and pace of political change, all can be modified to test different political settings. In fact, this module of the model can take a wide range of assumptions to fit different political agendas. Indicated power is an index between 0 an 1 where 0 represents no political power at all while 1 represents absolute power of the government. Government here could be a ruling individual, family, tribe, or party. The model does not distinguish between different rulers at different times and places because individual characteristics of the ruling class is not of importance for analysis of this study. Consequently, simulation results do not show competition between political rivals. It only shows the dynamics of political power of the incumbent ruler which is called here as "state" or "government" interchangeably.

According to the Katouzian's theory of arbitrary state and society (Langarudi and Radzicki, 2015), popularity of ruler gives him (them) the opportunity to gain more political power. So, the state popularity makes a political rise more likely. Utility of political power is another factor affecting the state power. As symptoms of social chaos—for instance, crime rates—increase in a society, utility of a powerful government who could control the chaos would increase. This could generate an space for the government to seize more power[15]. Controlling power of the government is also important to protect its political power. A government with significant controlling power could stay longer at helm. Finally, foreign debt imposes political pressure on the government. This pressure is represented by Eq. C.7.7.

$$ASP_t = 1 - \frac{1}{e^{\left(LPS_t \cdot ASPU_t \cdot ASC_t \cdot FDP_t \cdot PSPE\right)}} \tag{C.7.5}$$

ASP	=	Indicated state political power [Dimensionless]
LPS (C.7.11)	=	State popularity [Dimensionless]
ASPU (C.7.6)	=	Utility of state political power [Dimensionless]
ASC (C.7.35)	=	State controlling power [Dimensionless]
PSPE (C.7.3)	=	Elasticity of state political power [Dimensionless]

$$ASPU_t = \frac{LPCH_t}{LPCH_0} \cdot \frac{NSP}{LSP_t} \tag{C.7.6}$$

[15] As we will see later, chaos works as a double edged sword. Beside its positive impact on utility of power, it could reduce political power by declining political legitimacy of the government, and hence damaging its popularity.

ASPU	=	Utility of state political power [Dimensionless]
LPCH (C.7.8)	=	Perceived chaos [Dimensionless]
NSP (C.7.2)	=	Initial (normal) state political power [Dimensionless]
LSP (C.7.1)	=	State political power [Dimensionless]

$$FDP = \frac{1}{1 + \dfrac{\max(0, LD_t)}{NFE}} \tag{C.7.7}$$

FDP	=	Effect of foreign debt on the state power [Dimensionless]
LD (C.6.31)	=	International debt [$]
NFE (C.6.10)	=	Initial (normal) level of foreign exchange reserves [$]

Chaos is an indicator of arbitrariness in the society. Here we define chaos as any form of activity that breaks the rule of law in a society or any phenomenon that considerably changes the social order. Also note that it takes some time for the society to perceive full extent of the actual level of chaos.

$$LPCH_t = ACH_0 + \int_0^t \frac{ACH_\tau - LPCH_\tau}{TP} \cdot d\tau \tag{C.7.8}$$

LPCH	=	Perceived chaos [Dimensionless]
ACH (C.7.9)	=	Socio-political-economic chaos [Dimensionless]
TP (C.2.12)	=	Perception time delay [Year]

Chaos in the model depends on population of people who may break the rule of law. That includes parasites and corrupt government officers. If their relative population increases cases of chaos become more likely to happen. State popularity also plays a role in chaos. A discontent society is more prone to chaos. A minimum level of chaos (PCH) which represents the chaos imposed by the nature is also taken into account.

$$ACH_t = PCH + \frac{LCO_t + LP_t}{APOP_t \cdot LPS_t} \tag{C.7.9}$$

ACH	=	Socio-political-economic chaos [Dimensionless]
PCH (C.7.10)	=	Natural chaos [Dimensionless]
LCO (C.1.17)	=	Corrupt government officers: part of the government workforce who get involved in corrupt and illegal activities [Person]
LP (C.1.42)	=	Parasites: part of workforce who do not work but enjoy consuming of others' production [Person]
APOP (C.1.34)	=	Workforce population [Person]
LPS (C.7.11)	=	State popularity [Dimensionless]

$$PCH = 0.02 \tag{C.7.10}$$

PCH	=	Natural chaos [Dimensionless]

Classical macroeconomics is founded on an implicit premise that social welfare function includes only inflation and unemployment. The model here is assumed to contain more components including income equality, consumption, leisure, and public safety and security. From this point of view, popularity of the state depends on its performance. People expect the government to perform its functions including providing public services, national security and defense, public order and safety, etc. If a government fails to function at a reasonable level, its popularity declines.

$$LPS_t = LPS_0 + \int_0^t (RPSI_\tau - RPSD_\tau) \cdot d\tau \tag{C.7.11}$$
$$LPS_0 = 1$$

LPS	=	State popularity [Dimensionless]
RPSI (C.7.12)	=	Increase of the state popularity [1/Year]
RPSD (C.7.14)	=	Decrease of the state popularity [1/Year]

$$RPSI_t = \frac{\max(0, APS_t - LPS_t)}{TPSI} \tag{C.7.12}$$

RPSI	=	Increase of the state popularity [1/Year]
APS (C.7.16)	=	Indicated state popularity [Dimensionless]
LPS (C.7.11)	=	State popularity [Dimensionless]
TPSI (C.7.13)	=	Time delay for the state popularity to increase [Year]

$$TPSI = 5 \tag{C.7.13}$$

TPSI	=	Time delay for government popularity to increase [Year]

$$RPSD_t = \frac{-\min(0, APS_t - LPS_t)}{TPSD} \tag{C.7.14}$$

RPSD	=	Decrease of the state popularity [1/Year]
APS (C.7.16)	=	Indicated state popularity [Dimensionless]
LPS (C.7.11)	=	State popularity [Dimensionless]
TPSD (C.7.15)	=	Time delay for the state popularity to decrease [Year]

$$TPSD = 2 \tag{C.7.15}$$

TPSD	=	Time delay for government popularity to decrease [Year]

Government performance is divided into two broad categories: economic performance and political performance. These are not actual performance of the state but rather perception of the public. The state popularity then is an arithmetic average of these two factors. Weight of each factor in the function could vary though.

$$APS_t = AEL_t \cdot PWES + APL_t \cdot (1 - PWES) \tag{C.7.16}$$

APS	=	Indicated state popularity [Dimensionless]
AEL (C.7.18)	=	Economic performance of the state [Dimensionless]
PWES (C.7.17)	=	Weight of economy in the state popularity function [Dimensionless]
APL (C.7.25)	=	Political performance of the state [Dimensionless]

$$PWES = 0.5 \tag{C.7.17}$$

PWES	=	Weight of economy in the state popularity function APS [Dimensionless]

As mentioned above, performance here refers to the society's mental image of how well the government is working. This may be right or wrong. Economic performance of the government consists of three different elements. First element is unemployment. Government, especially in the resource-rich countries, is expected to lead the national economy towards full employment. Any unemployment rate above the natural level would cause social discontent. Magnitude of this effect could be modified and tested on the model through changes in the elasticity parameters in the state economic performance function (see Eq. C.7.18 below).

Second element affecting the image of the state's economic performance is the real consumption. Government can change level of consumption in the society through transfer payments or other public expenditures and investments. In the real world this can also contain a wide variety of public services such as health, education, etc. Considering the model's level of aggregation, all these government expenditures are reflected in the real consumption per capita. At the same time, this variable represents the effect of inflation too. As prices increase real consumption declines, ceteris paribus. Subsequently, economic performance of the government declines. Note that this indicator is compared with its remembered counterpart (*LRC*: C.7.21). As Frey and Stutzer (2010) argue, people get used to their circumstances when it comes to economic factors such as income and consumption.

People either compare their situation with their past or with others' situation (Frey and Stutzer, 2010). So, the third element is income equality. A decline in equality negatively impacts social welfare (Easterlin, 2001; Oishi et al., 2011) and thus, damages the state popularity.

$$AEL_t = (\frac{PNUR}{AUR_t})^{PUEE} \cdot (\frac{ARCPC_t}{LRC})^{PCEE} \cdot (\frac{AEQ_t}{AEQ_0})^{PQEE} \qquad \text{(C.7.18)}$$

AEL	=	Economic performance of the state [Dimensionless]
PNUR (C.1.49)	=	Natural unemployment rate [Dimensionless]
AUR (C.1.48)	=	Unemployment rate [Dimensionless]
PUEE (C.7.19)	=	Unemployment elasticity of government economic performance [Dimensionless]
ARCPC (C.7.20)	=	Real consumption per capita [$/(Person-Year)]
LRC (C.7.21)	=	Remembered consumption per capita [$/(Person-Year)]
PCEE (C.7.23)	=	Consumption elasticity of government economic performance [Dimensionless]
AEQ (C.4.1)	=	Income equality index [Dimensionless]
PQEE (C.7.24)	=	Income equality elasticity of government economic performance [Dimensionless]

$$PUEE = 1 \qquad \text{(C.7.19)}$$

PUEE	=	Unemployment elasticity of government economic performance [Dimensionless]

$$ARCPC_t = \frac{(1 - NNTPF) \cdot APC_t}{APOP_t \cdot LTPI_t} + \frac{NNTPF \cdot APC_t}{APOP_t \cdot LNTPI_t} \qquad \text{(C.7.20)}$$

ARCPC	=	Real consumption per capita [$/(Person-Year)]
NNTPF (C.4.29)	=	Initial (normal) fraction of production capacity allocated to non-traded goods sector [Dimensionless]
APC (C.2.23)	=	Private consumption [$/Year]
APOP (C.1.34)	=	Workforce population [Person]
LTPI (C.5.9)	=	Price index of traded goods [Dimensionless]
LNTPI (C.5.21)	=	Price index of non-traded goods [Dimensionless]

$$LRC_t = LRC_0 + \int_0^t \frac{ARCPC_\tau - LRC_\tau}{TPM} \cdot d\tau \qquad \text{(C.7.21)}$$
$$LRC_0 = ARCPC_0$$

LRC	=	Remembered consumption per capita [$/(Person-Year)]
ARCPC (C.7.20)	=	Real consumption per capita [$/(Person-Year)]
TPM (C.7.22)	=	Length of time people can remember [Year]

$$TPM = 5 \qquad \text{(C.7.22)}$$

TPM = Length of time people can remember [Year]

$$PCEE = 1 \qquad \text{(C.7.23)}$$

PCEE = Consumption elasticity of government economic performance [Dimensionless]

$$PQEE = 1 \qquad \text{(C.7.24)}$$

PQEE = Income inequality elasticity of government economic performance [Dimensionless]

Providing peace and safety is considered to be the most important political functionality of the government. Freedom must not be sacrificed though. This challenge of the state to create a balance between freedom and security is shown by the function AGQ (C.7.27) which implies that the government needs to control the chaos for maintaining its popularity but this control should not reduce freedom, otherwise, the governance quality declines. Again, the perception of security, freedom, or any other political performance measures could adapt to new circumstances (Frey and Stutzer, 2010; Saeed et al., 2013). Hence, the political performance is a comparison of current and remembered level of governance quality.

$$APL_t = \frac{AGQ_t}{LGQ_t} \tag{C.7.25}$$

APL	=	Political performance of the state [Dimensionless]
AGQ (C.7.27)	=	State governance quality [Dimensionless]
LGQ (C.7.26)	=	Remembered state governance quality [Dimensionless]

$$LGQ_t = LGQ_0 + \int_0^t \frac{AGQ_\tau - LGQ_\tau}{TPM} \cdot d\tau \tag{C.7.26}$$

$$LGQ_0 = 1$$

LGQ	=	Remembered state governance quality [Dimensionless]
AGQ (C.7.27)	=	State governance quality [Dimensionless]
TPM (C.7.22)	=	Length of time people can remember [Year]

$$AGQ_t = LFREE_t \cdot \frac{LPCH_0}{LPCH_t} \tag{C.7.27}$$

AGQ	=	State governance quality [Dimensionless]
LFREE (C.7.28)	=	Freedom [Dimensionless]
LPCH (C.7.8)	=	Perceived chaos [Dimensionless]

Control of the state and how it impacts freedom is also described in this section. A positive interpretation of political freedom is used here to define the term freedom as free exercise of social and group political rights without the fear of coercion or oppression[16]. From this point of view, freedom is mainly constrained by the coercive force of the government. Thus freedom is formulated to be negatively related to the state controlling power. However, a powerful government does not necessarily limit freedom. The coerciveness of the government could be affected by the extent to which it relies on taxes as a source of revenue. A government with considerable revenues from external sources such as natural resources is less reliant on—thus less accountable to—the public (Ross,

[16]See Berlin (1990) for a philosophical discussion on the issue.

2001, 2008; Acemoglu and Robinson, 2005). The significance of each of these effects might differ for different political systems. Many scholars believe that these differences arise from the quality of institutions (Acemoglu et al., 2003; Bulte et al., 2005; Mehlum et al., 2006; Luong and Weinthal, 2010). "Good" institutions, in their view, are responsible for sensitivity of the state coerciveness in response to different levels of controlling power and reliance on natural resource revenues. Freedom in a country such as Norway may not be affected by the state control or its reliability on natural resources as much as it may be in Nigeria. This concept is formulated by Eq. C.7.34 and affects freedom in Eq. C.7.30. Note that there is a delay for the indicated freedom to root in the foundation of the society. This is also true for the decline of the freedom [see Eq. C.7.28].

$$LFREE_t = LFREE_0 + \int_0^t \frac{AFREE_\tau - LFREE_\tau}{TFREE} \cdot d\tau \qquad \text{(C.7.28)}$$
$$LFREE_0 = 1$$

LFREE	=	Freedom [Dimensionless]
AFREE (C.7.30)	=	Indicated freedom [Dimensionless]
TFREE (C.7.29)	=	Time delay for freedom to be established [Year]

$$TFREE = 2 \qquad \text{(C.7.29)}$$

TFREE	=	Time delay for freedom to be established [Year]

$$AFREE_t = (\frac{LFT_t}{ASC_t})^{AEF_t} \qquad \text{(C.7.30)}$$

AFREE	=	Indicated freedom [Dimensionless]
LFT (C.7.31)	=	Freedom from share of tax in government revenues [Dimensionless]
AEF (C.7.34)	=	Elasticity of freedom [Dimensionless]
ASC (C.7.35)	=	State controlling power [Dimensionless]

$$LFT_t = LFT_0 + \int_0^t \frac{AFT_\tau - LFT_\tau}{TSTF} d\tau \qquad \text{(C.7.31)}$$
$$LFT_0 = 1$$

LFT = Smoothed freedom from share of tax in government revenues [Dimensionless]
AFT (C.7.33) = Freedom from share of tax in government revenues [Dimensionless]
TSTF (C.7.32) = Time to smooth effect of tax on freedom [Year]

$$TSTF = 5 \tag{C.7.32}$$

TSTF (C.7.32) = Time to smooth effect of tax on freedom [Year]

$$AFT = \frac{ATAX_t/RGR_t}{ATAX_0/RGR_0} \tag{C.7.33}$$

AFT = Freedom from share of tax in government revenues [Dimensionless]
ATAX (C.3.31) = Government tax revenues [$/Year]
RGR (C.3.30) = Government revenues [$/Year]

$$AEF = \frac{1}{1 + \dfrac{LGI_t}{LGI_0}} \tag{C.7.34}$$

AEF = Elasticity of freedom [Dimensionless]
LGI (C.1.26) = Number of good institutions [Dimensionless]

State controlling power depends on magnitude of the society's resources owned by the government. It also matters that what fraction of these resources are allocated to control vs. production. Please note that only non-corrupt government workforce contribute to the control resources. Political power of the government is another crucial factor to determine controlling power of the state. A government without effective political leadership will not be able to elicit the full potential of its controlling resources.

$$ASC_t = \Big(\frac{LSP_t \cdot FCR_t + NGW \cdot NCRF \cdot LSP_0}{2 \cdot NGW \cdot NCRF \cdot LSP_0}\Big)^{PESC} \tag{C.7.35}$$

ASC	=	State controlling power [Dimensionless]
LSP (C.7.1)	=	State political power [Dimensionless]
FCR (C.7.38)	=	Current state of control resources [Person]
NGW (C.1.16)	=	Initial (normal) government sector workforce [Person]
NCRF (C.7.36)	=	Initial (normal) fraction of government resources allocated to control means [Dimensionless]
PESC (C.7.37)	=	Elasticity of state control [Dimensionless]

$$NCRF = 0.4 \tag{C.7.36}$$

NCRF = Initial (normal) fraction of government resources allocated to control means [Dimensionless]

$$PESC = 0.5 \tag{C.7.37}$$

PESC = Elasticity of state control [Dimensionless]

$$FCR_t = 0.5 \cdot LGW_t \cdot LCRF_t \cdot \Big(1 + (\frac{LGC_t}{NGC})^{PCEC}\Big) \tag{C.7.38}$$

FCR	=	Current state of control resources [Person]
LGW (C.1.15)	=	Workforce employed in the government sector [Person]
LCRF (C.7.40)	=	Fraction of government resources allocated to control means [Dimensionless]
LGC (C.3.1)	=	Government capital [$]
NGC (C.3.2)	=	Initial (normal) government capital [$]
PCEC (C.7.39)	=	Capital elasticity of state control [Dimensionless]

$$PCEC = 0.1 \tag{C.7.39}$$

PCEC (C.7.39) = Capital elasticity of state control [Dimensionless]

It takes some time for resources to fully reallocate:

$$LCRF_t = LCRF_0 + \int_0^t \frac{ACRF_\tau - LCRF_\tau}{TCRF} \tag{C.7.40}$$
$$LCRF_0 = NCRF \cdot d\tau$$

LCRF	=	Fraction of government resources allocated to control means [Dimensionless]
NCRF (C.7.36)	=	Initial (normal) fraction of government resources allocated to control means [Dimensionless]
ACRF (C.7.42)	=	Indicated fraction of resources that must be allocated to control [Dimensionless]
TCRF (C.7.41)	=	Time delay for reallocation of state control resource [Year]

$$TCRF = 5 \tag{C.7.41}$$

TCRF	=	Time delay for reallocation of state control resource [Year]

The way the government allocates its resources is pretty simple. Reallocation process is based on comparison between economic and political performance of the state. If political performance is relatively low i.e. (based on our definition) government has not been very successful in maintaining stability, peace, safety, and security, then more resources would be allocated to control. In contrast, if economic performance is relatively low, less resources would be allocated to control which means that more resources shift towards production. Different governments may weigh each of these elements differently. This variation could be tested by the parameter $PWEC$ (C.7.43).

$$ACRF_t = NCRF \cdot FEPC_t{}^{PWEC} \cdot FPPC_t{}^{1-PWEC} \tag{C.7.42}$$

ACRF	=	Indicated fraction of resources that must be allocated to control [Dimensionless]
NCRF (C.7.36)	=	Initial (normal) fraction of government resources allocated to control means [Dimensionless]
PWEC (C.7.43)	=	Weight of economy in government resource allocation policy [Dimensionless]
FEPC (C.7.47)	=	Effect of state economic performance on fraction of resources allocated to control [Dimensionless]
FPPC (C.7.44)	=	Effect of political performance on fraction of resources allocated to control [Dimensionless]

$$PWEC = 0.5 \tag{C.7.43}$$

PWEC	=	Weight of economy in government resource allocation policy [Dimensionless]

Effect of political performance on the share of control of total government resources is represented by Eq. C.7.44. Shape and variation of this function are depicted in Fig. C.7.1.

$$FPPC_t = \frac{1}{(1 - NCRF) \cdot (LPPP_t^{PPPC}) + NCRF} \tag{C.7.44}$$

FPPC	=	Effect of political performance on fraction of resources allocated to control [Dimensionless]
NCRF (C.7.36)	=	Initial (normal) fraction of government resources allocated to control means [Dimensionless]
LPPP (C.7.46)	=	Perceived political performance [Dimensionless]
PPPC (C.2.14)	=	Political performance elasticity of control resource fraction [Dimensionless]

$$PPPC = 2 \tag{C.7.45}$$

PPPC	=	Political performance elasticity of control resource fraction [Dimensionless]

Receiving feedback from the society to evaluate political performance is a challenge per se. Indeed, many times governments could not perceive the situation correctly, or they perceive it with a delay, at best. This phenomenon is reflected by Eq. C.7.46.

$$LPPP_t = LPPP_0 + \int_0^t \frac{APL_\tau - LPPP_\tau}{TP} \cdot d\tau \tag{C.7.46}$$
$$LPPP_0 = 1$$

LPPP	=	Perceived political performance [Dimensionless]
APL (C.7.25)	=	Political performance of the state [Dimensionless]
TP (C.2.12)	=	Perception time delay [Year]

Eq. C.7.47 represents the effect of perceived economic performance on fraction of resources that the state allocates to control. Variation of this function is demonstrated in Fig. C.7.2.

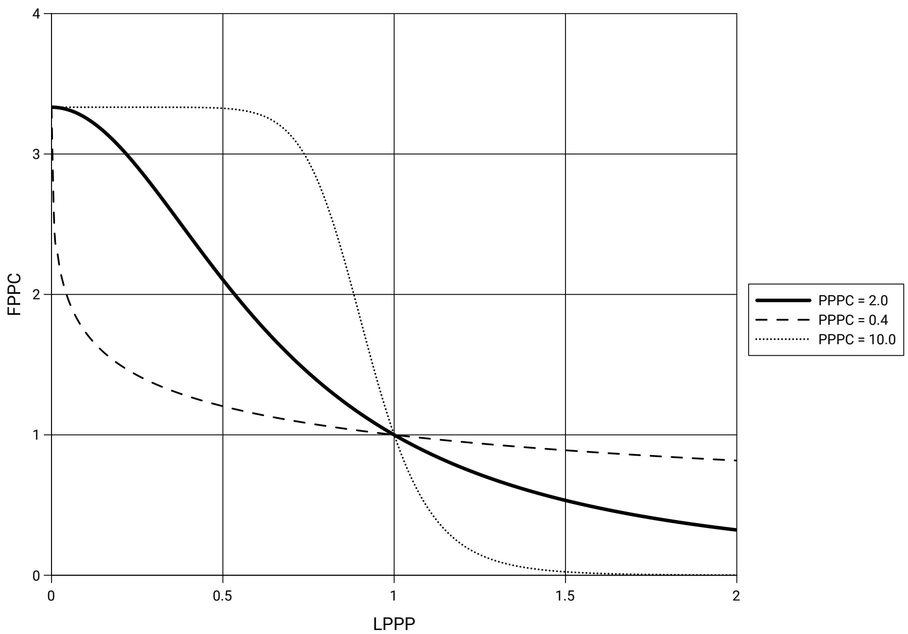

Figure C.7.1: Effect of political performance on control resource fraction

$$FEPC_t = \frac{(1+PEPC)/\left(1+e^{-\ln\left(\frac{1+NCRF}{1-NCRF}\right)\cdot LPEP}\right)-1}{(1+PEPC)/\left(1+e^{-\ln\left(\frac{1+NCRF}{1-NCRF}\right)}\right)-1} \quad \text{(C.7.47)}$$

FEPC	=	Effect of state economic performance on fraction of resources allocated to control [Dimensionless]
PEPC (C.7.48)	=	Concaveness of the function $FEPC$ (effect of state economic performance on fraction of resources allocated to control) [Dimensionless]
NCRF (C.7.36)	=	Initial (normal) fraction of government resources allocated to control means [Dimensionless]
LPEP (C.7.49)	=	Perceived economic performance [Dimensionless]

$$PEPC = 1.2 \quad \text{(C.7.48)}$$

PEPC	=	Concaveness of the function $FEPC$ (effect of state economic performance on fraction of resources allocated to control) [Dimensionless]

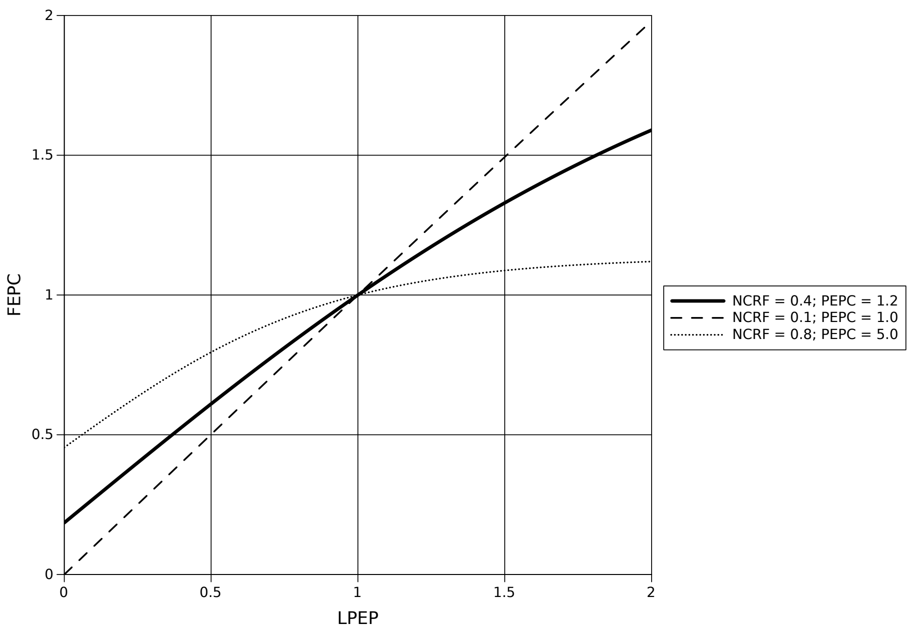

Figure C.7.2: Effect of economic performance on state control resource fraction

Similar to political performance, economic performance must be perceived which may take some time.

$$LPEP_t = LPEP_0 + \int_0^t \frac{AEL_\tau - LPEP_\tau}{TP} \cdot d\tau \tag{C.7.49}$$

$$LPEP_0 = 1$$

LPEP	=	Perceived economic performance [Dimensionless]
AEL (C.7.18)	=	Economic performance of the state [Dimensionless]
TP (C.2.12)	=	Perception time delay [Year]

C.8 Oil Export

Oil export in the model is exogenous. Nonetheless, any possible scenario could be applied to the variable in order to test the model. These scenarios are included in the default version of the model but other cases may be added too:

- a constant level of oil export which is a fraction of total economic output (Eq. C.8.2)—all other scenarios only work when this constant export is non-zero;
- an oscillatory level of oil export (see Eq. C.8.4);
- a bell-shape behavior over time for the level of oil export (Eq. C.8.7); and
- a S-shape behavior over time for oil export which is applied by a logistic function (Eq. C.8.10).

The functions introduced in this section are flexible to a great extent. The parameters provided here could be used to change the shape and range of the corresponding functions.

$$AOEXP_t = AOILC_t \cdot AOILS_t \cdot AOILB_t \cdot AOILL_t \tag{C.8.1}$$

AOEXP	=	Oil Export [$/Year]
AOILC (C.8.2)	=	Constant oil export [$/Year]
AOILS (C.8.4)	=	An oscillatory multiplier for oil export [Dimensionless]
AOILB (C.8.7)	=	Bell-shape multiplier for oil export [Dimensionless]
AOILL (C.8.10)	=	logistic multiplier for oil export [Dimensionless]

$$AOILC_t = \begin{cases} 0 & ,t \leq 1 \\ NO_t \cdot POILC & ,t > 1 \end{cases} \tag{C.8.2}$$

AOILC	=	Constant oil export [$/Year]
NO (C.4.19)	=	Initial (normal) total output of the economy [$/Year]
POILC (C.8.3)	=	Fraction of initial level of total output as constant oil export multiplier [Dimensionless]

$$POILC = 0 \tag{C.8.3}$$

POILC	=	Fraction of initial level of total output as constant oil export multiplier [Dimensionless]

$$AOILS_t = 1 + POILA \cdot \sin(t \cdot POILF) \tag{C.8.4}$$

AOILS	=	An oscillatory multiplier for oil export [Dimensionless]
POILA (C.8.5)	=	Amplitude of oscillation for oil export [Dimensionless]
POILF (C.8.6)	=	Frequency of oscillation for oil export [Dimensionless]

$$POILA = 0 \tag{C.8.5}$$

POILA = Amplitude of oscillation for oil export [Dimensionless]

$$POILF = 0.4 \tag{C.8.6}$$

POILF = Frequency of oscillation for oil export [Dimensionless]

$$AOILB_t = 1 - POILBS + \frac{10 \cdot POILBS}{POILSD \cdot \sqrt{2\pi} \cdot e^{\frac{\left((10t-5T)/T\right)^2}{2 \cdot POILSD^2}}} \tag{C.8.7}$$

AOILB	=	Bell-shape multiplier for oil export [Dimensionless]
POILBS (C.8.8)	=	Switch to turn on bell-shape multiplier for oil export [Dimensionless]
POILSD (C.8.9)	=	Standard deviation of the bell curve for oil export [Dimensionless]
T (C.8.14)	=	The final time for the simulation [Year]

$$POILBS = 0 \tag{C.8.8}$$

POILBS = Switch to turn on bell-shape multiplier for oil export [Dimensionless]

$$POILSD = 1 \tag{C.8.9}$$

POILSD = Standard deviation of the bell curve for oil export [Dimensionless]

$$AOILL_t = 1 - POILS + \frac{2 \cdot POILS}{1 + e^{\frac{-10 \cdot PSOIL(t - POILM \cdot T)}{T}}} \tag{C.8.10}$$

AOILL	=	logistic multiplier for oil export [Dimensionless]
POILS (C.8.11)	=	Switch to turn on logistic multiplier for oil export [Dimensionless]
PSOIL (C.8.12)	=	Slope of the logistic multiplier for oil export [Dimensionless]
POILM (C.8.13)	=	Sigmoid midpoint of logistic multiplier for oil export [Dimensionless]
T (C.8.14)	=	The final time for the simulation [Year]

$$POILS = 0 \tag{C.8.11}$$

POILS = Switch to turn on logistic multiplier for oil export [Dimensionless]

$$PSOIL = 1 \tag{C.8.12}$$

PSOIL = Slope of the logistic multiplier for oil export [Dimensionless]

$$POILM = 0.5 \tag{C.8.13}$$

POILM = Sigmoid midpoint of logistic multiplier for oil export [Dimensionless]

$$T = 50 \tag{C.8.14}$$

T = The final time for the simulation [Year]

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